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FEBRUARY, 1942

PROGRESS OF STRATIGRAPHIC STUDIES IN CALIFORNIA[1]

E. R. ATWILL[2]
Los Angeles, California

ABSTRACT

Many geologists in California have been converted to the belief that the stratigraphic type of trap will provide a majority of future oil fields in the state. Therefore, considerable impetus has been given to the study of sedimentation from every possible approach.

This paper presents the various methods now used in California to study sedimentation and stratigraphy, describing briefly the innovations to date and analyzing the future trend of this type of work.

INTRODUCTION

For several years prior to 1939, California geologists thought almost exclusively in terms of the reflection seismograph as an exploratory approach to finding oil fields. Structural details beneath flat, alluvium-covered valleys were rapidly mapped with a reasonable degree of accuracy and new fields were discovered in quick succession. The personnel of most geological departments was completely absorbed in making the most of this new method of exploration. Field mapping was reduced to a minimum; stratigraphic anomalies were sometimes noted, but usually were laid aside. The emphasis everywhere was placed on locating structure, much as in the early days of surface geologic study.

Gradually, most of the available territory adapted to seismograph mapping was covered, much of it tested, and geologists began to experience difficulty in finding areas of promise for this type of mapping. A period of transition was entered, during which a new method of approach was sought. Time was taken to look back over the history of

[1] Read by title before the Association at Houston, April 4, 1941. Manuscript received, September 2, 1941.

[2] Research geologist, Union Oil Company of California. Acknowledgment is made especially to E. W. Galliher who contributed notably to this paper but who declined to act as co-author. Further acknowledgments are made to E. B. Noble and H. W. Hoots for their helpful criticism and suggestions.

successes and failures, and suddenly it was realized that more than 50 per cent of California oil fields are dependent upon some form of stratigraphic control. Wide general interest was aroused over the idea of stratigraphic accumulation, and a careful check was made of all existing methods of stratigraphic study.

PRESENT METHODS OF STUDY

In a broad way, all present methods of stratigraphic study are used in the work of correlating surface and subsurface geology. These methods can be classified and their present trends indicated as follows.

A. DETAILED EXAMINATION OF WELL DATA

In the past, fossil identification was considered the most important step in an examination of well cores, principally from the standpoint of correlation between wells. Now, although paleontology is still useful and necessary, more stress is placed on vertical and lateral variations in lithology. Attempts are made to discover the source and transport direction of sand bodies, to trace a shore-line condition into an area where structure will combine with it favorably to suggest a trap. Electrical logs are used to show the variation in sands from one locality to another; and, where cores are available, core-analysis data are used to indicate the approach to permeability pinch-outs.

B. STUDY OF SURFACE GEOLOGY

Surface geology naturally contributes to a knowledge of the structure of an area. For the purpose of detecting a stratigraphic trap, though, its greatest usefulness is as a yardstick beside which a subsurface section can be measured. Realizing this, many of the companies have started a program of very detailed field mapping around the borders of petroliferous basins, to acquire complete data on exposed formations.

Areas previously covered by field geologists are now being reworked with a new technique. Smaller lithologic units are mapped; more individual marker beds are traced; local as well as regional gradations in texture are plotted. The absence of certain intervals, as compared with a normal stratigraphic section, are especially noted. Paleontologists are working with field men in the collection of surface sections to establish more accurately a tie between cartographic units and subsurface divisions.

With this new fund of information ultimately at hand, downdip thickening—resulting from the introduction of new formations, the increased thickness of exposed formations, or pre-depositional faulting

FIG. 1.—View of Estero Bay and Morro Rock, San Luis Obispo County, looking northward. Shows portion of well developed sand spit which extends south from Morro Rock for about 5 miles and forms a subsidiary bay or lagoon. (Courtesy of Fairchild Aerial Surveys, Inc.)

FIG. 2.—More complete view of lagoon at Morro Bay, showing town of Morro Bay. Silting processes are carried on by several small streams which empty into the lagoon and which maintain egress to the sea over a shallow sill near Morro Rock. (Courtesy of Fairchild Aerial Surveys, Inc.)

FIG. 3.—Portion of coast line in northern Humboldt County near town of Orick, looking westward. Barrier sand reefs have completely enclosed a series of inlets. At Maple Creek, silting process is still in early stage, suggesting recent completion of barrier. At Prairie Creek, inlet has been entirely filled and creek empties directly into sea. Original mouth of inlet was narrower and barrier was formed more rapidly. (Courtesy of Fairchild Aerial Surveys, Inc.)

FIG. 4.—Portion of 17-foot core taken from sea bottom in Gulf of California. White layers are very diatomaceous; darker layers contain some silt. Together they are thought to represent an annual interval of deposition. (Courtesy of Scripps Institution of Oceanography.)

—can be determined, and the most favorable areas for further study or testing can be delimited.

C. STUDY OF SEISMOGRAPH SECTIONS

Seismograph sections chiefly reveal the structure of an area and generally succeed in bridging the correlation gap between well data and surface mapping. While the portrayal of structure is the most important function of the seismograph, it is also being used to locate angular unconformities, excessive thickening of beds and sand pinch-outs. In the last instance, the usefulness of the seismograph has not yet been fully demonstrated. However, in the case of a homogeneous body of shale with very few reflections occurring between its upper and lower limits, the sudden appearance at its base of additional reflections which increase in total number as they ascend in the section strongly suggests a changing lithology.

D. STUDY GROUPS

As a further outgrowth of this renewed interest by geologists in the potentialities of stratigraphic traps, sedimentation study groups have been organized in various sections. These groups attempt to review fundamental principles, consider new concepts, and investigate the general field of literature on sedimentation. In addition, they work out as a group certain problems dealing with the origin, depositional conditions and general petrography of some particular formation.

An example of the practical experiments occasionally made for first-hand study of sedimentary processes is that recently performed by Manley L. Natland. He constructed a small artificial lake, and, by slowly feeding sediments to a controlled stream of low gradient, gradually filled the lake. The water was frequently drained off and photographs taken during different stages of the process. At the conclusion of the experiment, the whole set of beds was sliced open and cross-section pictures taken.

E. STUDY OF SHORE-LINE PROCESSES

More and more attention is being given to a study of recent shore-line processes—not alone by the universities, but by men in the field.

Many areas along the coast of California are natural laboratories where geologists are observing sedimentation at work. Morro Bay is an excellent example, showing a pronounced offshore sand bar with an inner lagoon that is slowly filling up with silty clay (Figs. 1 and 2). A similar ancient condition is believed to have existed at Coalinga, resulting in the formation of the prolific Eocene oil fields which have been recently discovered there. The cross sections in Figures 5 and 6

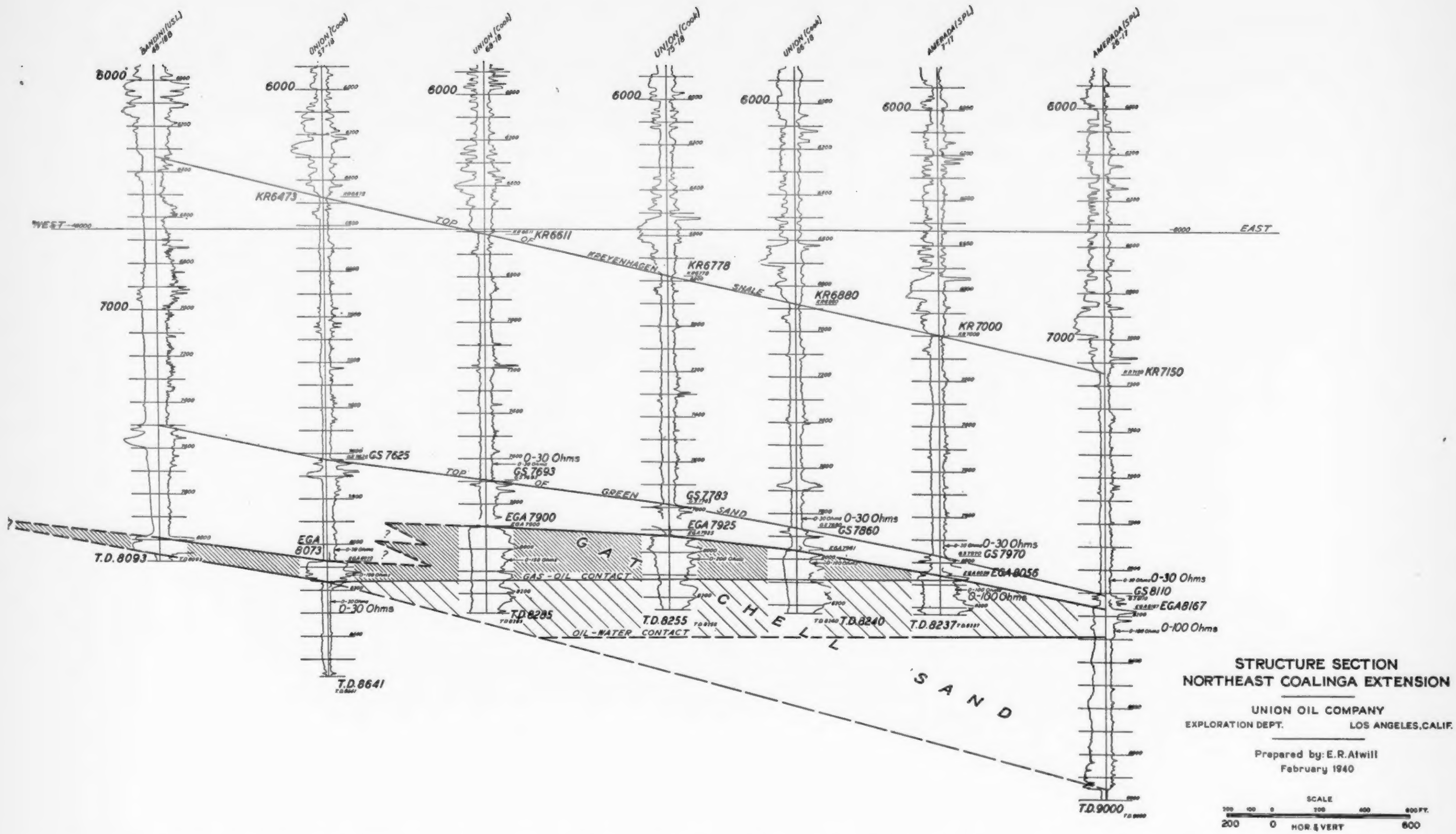


FIG. 5.—Structure section at Northeast Coalinga oil field, showing bar-like character of producing sand (Gatchell). Silt beds beneath green sand updip are very carbonaceous, even coal-bearing in places, suggesting lagoonal conditions. Sand thickens and rises in stratigraphic section seaward from ancient shore line, and may have existed above sea-level farther east.

indicate the bar-like nature of the producing sand. Silt beds farther updip carry a high carbonaceous content and in one or two places coal seams are present, suggesting lagoonal conditions. Another example of this type of stratigraphic trap being formed at present can be seen north of Humboldt Bay (Fig. 3) where a series of coves have been completely enclosed by sand bars, which, incidentally, exhibit unusually straight ocean shore lines.

Similar to these studies is the very detailed work being done by the Scripps Institution of Oceanography in the Gulf of California, which is a body of water some 600 miles long, 100 miles wide and more than 10,000 feet deep at its mouth. Revelle has noted that offshore winds blowing down the gulf establish a cycle during which the silica-depleted upper waters are driven out to sea and are replaced by silica-rich waters from the open ocean. This annual replenishment of silica permits huge colonies of diatoms to flourish in the gulf. During the period of winter winds, great numbers of diatoms die and are deposited on the bottom. Figure 4 shows part of a 17-foot core taken from the gulf. The white layers in most cases are composed entirely of diatoms, the darker layers containing some silt—representing together possibly an annual varve. Cores such as this are taken at sea depths up to 12,000 feet and assist in estimating rates of deposition. It is reported further that occasionally gas is detected in the cores as revealed by flash tests.

This whole program of work is of great value to all stratigraphers and of particular interest to California geologists because the present conditions in the gulf are believed to be quite similar to those that existed in the Miocene seas of California. The gulf, like the ancient San Joaquin and Salinas embayments, is a long, narrow arm of sheltered water with abundant diatom life which contributes steadily and rapidly to the growth of bottom sediments.

In addition, the Institution is carrying on laboratory studies of living forms of diatoms and Foraminifera, and of sediments collected on the continental shelves by means of sediment traps. Furthermore, submarine profiles off the coast of southern California, showing the position and relative length of cores taken, and the location of offshore basins are plotted. Figure 7 presents graphically the inverse proportion between grain size and organic content in a series of cores, and is typical of still another phase of the careful, analytical work being done by the Institution.

FUTURE TRENDS

For the future, it seems as though greater use could be made of the reflection seismograph in detecting the presence of lithologic

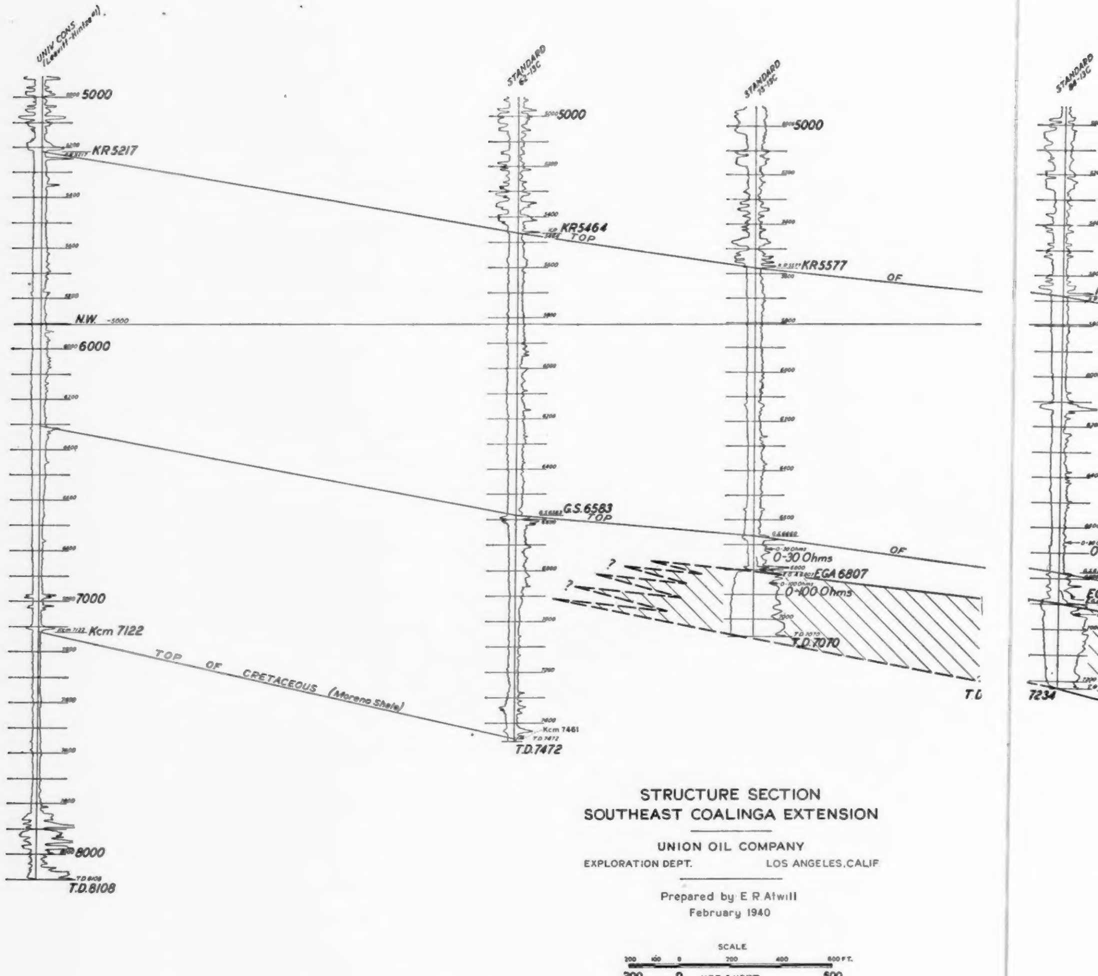
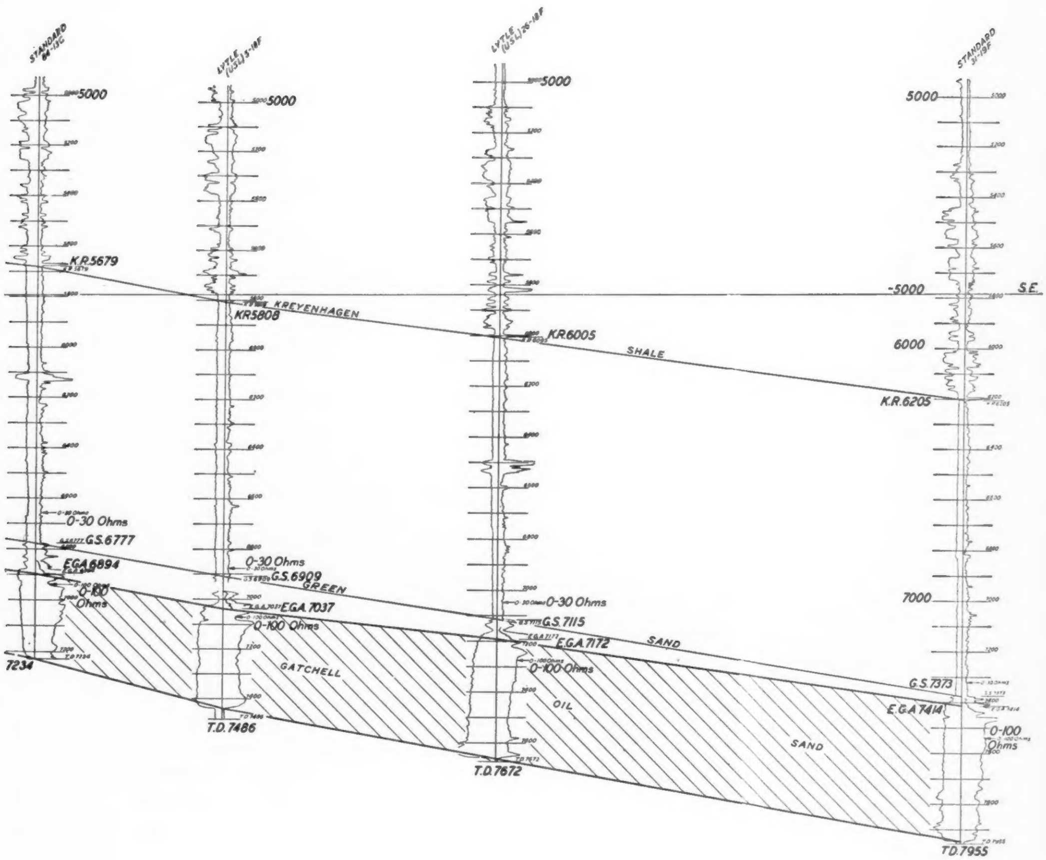


FIG. 6.—Structure section at Southeast Coalinga oil field. Shows more abrupt termination updip of Gatchell sand than



sand than in Figure 5. Position of this section is about 6 miles due south of one made for Northeast Coalinga

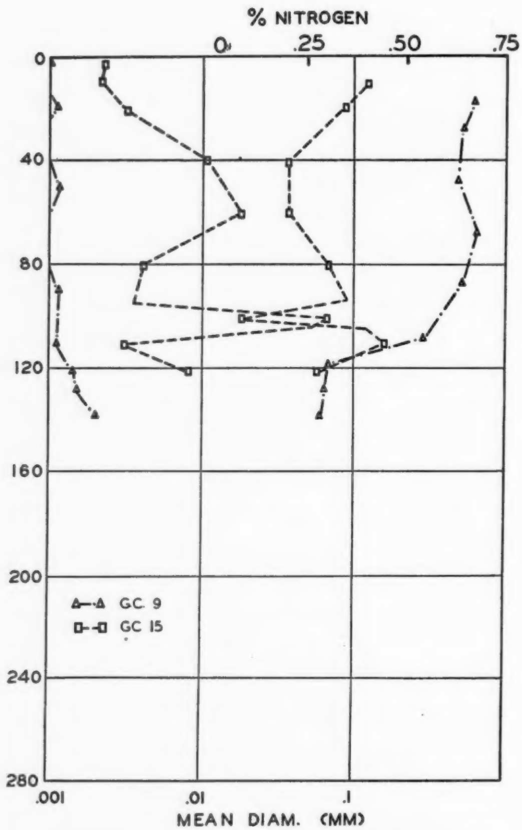


FIG. 7.—Graph showing inverse proportion of grain size (scale at base of graph) to organic content (scale at top of graph). Scale at left measures length of core in centimeters. (Courtesy of Scripps Institution of Oceanography.)

changes. Some geologists believe that this can be accomplished with the magnetometer under certain ideal conditions. More research in this direction should be encouraged.

There is an increasing number of 12,000-foot and 13,000-foot wells being drilled in California, many of which have penetrated the complete sedimentary section in the deeper portions of petroliferous geosynclines. These wells have focused some attention on sediment-basement complex relations, and perhaps new ideas may be required to utilize fully the facts thus revealed. It is conceivable that interpretations made to explain conditions near the shallow rim may not be successfully applied to these deeper areas.

Finally, it might be advisable to devote more time to the construction of paleogeographic and isopach maps of various sorts. Such maps can be expanded to a regional scale, showing the distribution of shale, facies changes from shale to sand or from marine to continental beds, changes in permeability, in carbonaceous or fossil content, as well as sand thicknesses. In this manner, it should be possible to narrow the search for the most favorable types of stratigraphic conditions. An example of this kind of regional study was presented at the Houston meeting of the Association, April 4, 1941, by Rollin Eckis, in his paper entitled "The Stevens Sand of Southern San Joaquin Valley, California."

In conclusion, it should be said that there is an increasing necessity for the drilling of information holes, even when an oil accumulation is not suggested by the evidence at hand. The extra expense attached to such programs may for a while retard this general approach to finding oil fields. In the opinion of the writer, however, this expense will be ultimately justified: first, by providing additional working material, second, by eliminating many unnecessary and costly wildcat wells, and third, by the discovery of oil fields of the stratigraphic type which already compose more than 50 per cent of the present producing fields in the state.

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UPPER CRETACEOUS FORMATIONS AND FAUNAS OF SOUTHERN CALIFORNIA[1]

WILLIS PARKISON POPENOE[2]
Pasadena, California

ABSTRACT

Rocks of Upper Cretaceous age crop out in three areas in the vicinity of Los Angeles, southern California. The section in the northern Santa Ana Mountains consists of 2,600 feet (more or less) of conglomerates, shales, and sandstones. These are divided into three formations, of which the upper two are further divisible into two members each. The rich faunas from the shales and sandstones are divisible into two major faunal assemblages that have but few species in common. The older assemblage is subdivisible into two minor faunal divisions. The younger assemblage is similarly divisible into three minor faunal divisions.

The Cretaceous beds of the Santa Monica Mountains consist of more than 8,000 feet of coarse clastics. These are nearly unfossiliferous with the exception of a 300-foot sandstone bed near the top of the section. This bed contains a fauna that is correlated with the highest faunal subdivision of the Santa Ana Mountains.

The Simi Hills Cretaceous consists of more than 6,000 feet of shales and sandstones. Only the lowermost 500 feet plus of this section has yielded fossils. The fossiliferous beds are correlated with the uppermost two minor faunal divisions of the Santa Ana Mountains.

Introduction

Since the time of Whitney and Gabb the presence of thick and richly fossiliferous beds of Upper Cretaceous age in California has been well known. Geologists have mapped the areal distribution of these beds in many places and paleontologists have described many of the fossil species found in them. Little has yet been done to distinguish the separate rock formations or to determine the succession of faunas and the stratigraphic positions and geologic ranges of the contained fossil species. This lack of detailed knowledge has prevented trustworthy correlations of the various exposures of Cretaceous beds found in California and elsewhere along the Pacific slope, and has made difficult an understanding of the geologic history of the Pacific Coast during Upper Cretaceous time.

This report summarizes the results of the first of a series of projected studies of the stratigraphy and paleontology of selected Upper Cretaceous sections in the Pacific Coast region. The exposures discussed here all lie in the vicinity of Los Angeles in southern California. The stratigraphy and fauna of the Santa Ana Mountains have been treated in some detail. The study of the Cretaceous formations and faunas of the Santa Monica Mountains and of the Simi Hills is less complete, but a provisional correlation of these latter deposits with those of the Santa Ana Mountains is suggested.

[1] Manuscript received, August 2, 1941.

[2] Balch Graduate School of the Geological Sciences, California Institute of Technology.

The principal conclusions reached in this study are three. 1. The Cretaceous sediments of the Santa Ana Mountains are divisible into three formations, of which the upper two are further subdivisible into two members each. 2. The Cretaceous faunas of the Santa Ana Mountains are divisible into two very distinct major faunal assemblages. The older assemblage contains two less distinct minor faunal divisions; the younger assemblage similarly is made up of three faunal divisions. 3. The known faunas of the Simi Hills and the Santa Monica Mountains are most closely related to the youngest faunal divisions of the Santa Ana Mountains and are tentatively correlated with them.

LOCATION OF AREAS

The Santa Ana Mountains are a northwesterly trending range lying about 50–75 miles southeast of Los Angeles. The range ends at the north along the Santa Ana River. The boundary between Orange and Riverside counties approximately follows the range crest. The Cretaceous deposits of the mountains crop out in a rudely triangular patch on the southwest slope of the range in the region between Trabuco and Santa Ana canyons. The Cretaceous areas of the Simi Hills are situated on the southeast and east flanks of the hills, which lie about 25 miles northwest of Los Angeles, on both sides of the Los Angeles-Ventura county line. The Cretaceous exposures of the Santa Monica Mountains crop out principally on the south slope of the mountains about 20 miles west of the main business district of Los Angeles and 5 or 6 miles northwest of the city of Santa Monica. The general locations of these exposures, and their relationships to one another and to Los Angeles are shown on the index map of southern California (Fig. 1).

REVIEW OF PREVIOUS WORK

Previous to 1914, little critical work was published on the Cretaceous rocks of southern California. Goodyear (1),[3] Fairbanks (2), Cooper (3), J. P. Smith (4), and F. M. Anderson (5) at one time or another referred to the presence of Cretaceous rocks in the Santa Ana Mountains and in the Simi Hills, and the last three authors described a number of fossil species from these localities. Packard (6) in 1914, in an account contributed to a general paper by R. E. Dickerson, gave a preliminary account of the stratigraphy of the Cretaceous beds of the Santa Ana Mountains. The same author (7) followed with a report in 1916 discussing the Cretaceous fauna of the region in some detail. One hundred thirty-one forms of invertebrate fossils were listed in the

[3] Numbers in parentheses refer to the bibliography at the end of this report.

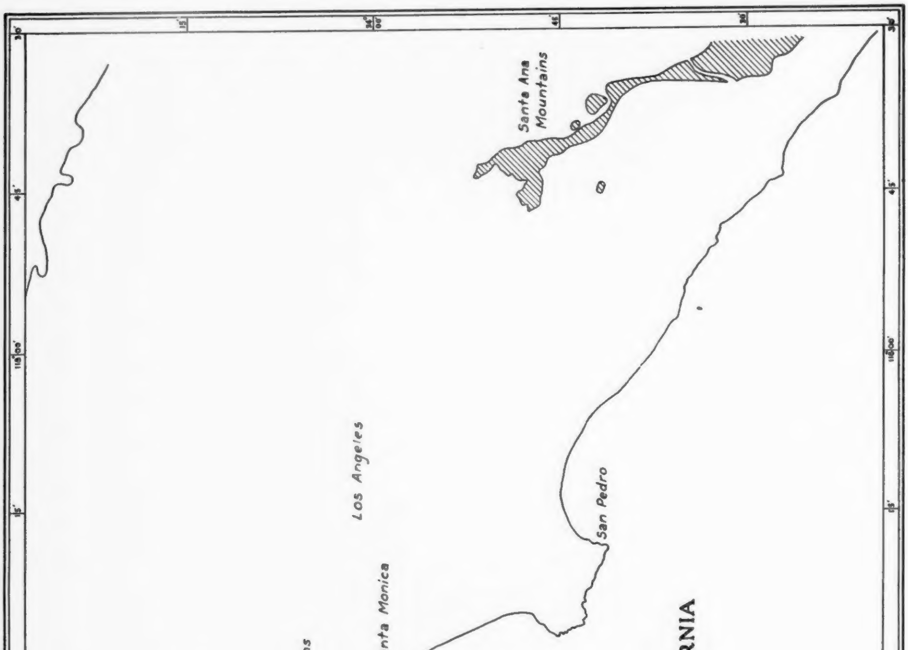


Fig. 1
SKETCH MAP
OF THE
VICINITY OF LOS ANGELES, CALIFORNIA
SHOWING THE LOCATION OF
CRETACEOUS EXPOSURES
After Reed and Hollister
0 5 10 15
Scale in Miles.
N
Simi Hills
Santa Monica Mountains
Santa Monica
Los Angeles
San Pedro
Santa Ana Mountains

FIG. 1

fauna, three faunal zones were recognized, and a preliminary correlation of the youngest faunal zone (the "*Tellina*" *ooides* zone = division of *Metaplacenticeras pacificum* of the present paper) with the "Type Chico" of Chico Creek was presented. The distinctive characters of the lowest faunal zone were recognized and briefly mentioned. Waring (8) in 1917 discussed the distribution of Upper Cretaceous rocks in the Simi Hills and the Santa Monica Mountains, published a faunal list from the two areas, and described a number of new species. Packard (9) in 1922 published descriptions of 34 new species of mollusks from the Santa Ana Mountains. Kew (10) in 1924 published a geologic map of parts of Los Angeles and Ventura counties showing the distribution of Cretaceous rocks in the Simi Hills, and included a discussion of the Cretaceous stratigraphy of the region in the accompanying report. English (11) in 1926 published a geologic report and map of the Puente Hills and northern Santa Ana Mountains, showing the distribution of the Cretaceous in the Santa Ana Mountains north of Silverado Canyon. Hoots (12) in 1930 published a general geological report and map of the eastern Santa Monica Mountains, showing the distribution of the Cretaceous deposits of that region. The report included a list of Cretaceous fossils identified by W. P. Woodring. Moore (13) in 1930 mapped and reported upon an area in the southern Santa Ana Mountains south of Silverado Canyon, including a considerable area of Cretaceous. He divided the Cretaceous into four formations on the basis of lithology and discussed some of the faunal characteristics of the beds. Popenoe (14) in 1937 presented a preliminary stratigraphic classification of the Santa Ana Mountains Cretaceous, and described and discussed a number of new or imperfectly known species.

ACKNOWLEDGMENTS

Thanks are due the following associates who have aided the writer in various ways during the investigation summarized here: J. P. Buwalda and Chester Stock of the California Institute of Technology, who have given general supervision and encouragement; R. M. Kleinpell for criticism of the manuscript; Bernard N. Moore for permission to use his excellent collection of Cretaceous fossils from the Santa Ana Mountains; H. D. B. Wilson for permission to use his stratigraphic data on the Cretaceous of the Santa Monica Mountains; Frank M. Anderson of the California Academy of Sciences, and L. W. Stephenson, J. B. Reeside, Jr., W. P. Woodring, and Ralph B. Stewart of the U. S. Geological Survey for courtesies and critical advice offered during the study of the fauna; and David P. Willoughby for aid in preparation of the maps and charts.

Cretaceous Formations of Santa Ana Mountains

STRATIGRAPHY

GENERAL FEATURES

The Cretaceous strata of the Santa Ana Mountains are here divided on a lithologic basis into five units, grouped into three formations, of which the upper two formations consist of two members each. Except for local areas where parts of the section are missing due to faulting or overlap these units may be recognized from end to end of the area of outcrop. A generalized section of the Cretaceous and associated formations as discussed is as follows.

Eocene
- Martinez formation.—Prevailingly light-colored sandstones, conglomerates and shales with some coal seams. In part marine

Unconformity

Upper Cretaceous
- Williams formation
  - Pleasants member.—Light-colored shaly sandstones with many beds of intercalated calcareous fossiliferous sandstone. Average thickness, 300 feet, ±
  - Schulz member.—Light-colored coarse arkosic sandstones with numerous beds of well rounded boulders. Unfossiliferous? Average thickness, 200 feet ±

Disconformity

- Ladd formation
  - Holz member.—Dark bluish to brownish gray micaceous sandy shale or siltstone with interbedded arkosic sandstones, calcareous concretionary beds, and nonpersistent coarse conglomerate lenses. Highly fossiliferous in the upper half. Thickness averages 1,000–1,500 feet
  - Baker Canyon member.—Gray to brown, massive to thick-bedded boulder conglomerate below, grading up into thick-bedded to shaly arkosic soft brown sandstones above. Sandstones generally highly fossiliferous. Thickness averages 200–300 feet

Cretaceous?
- Trabuco formation.—Soft red friable deeply weathered boulder conglomerate with some interbedded thin lenses of red cross-bedded sandstone. Unfossiliferous. Thickness, more than 300 feet

Profound unconformity

Pre-Cretaceous
- Basement complex.—Metamorphosed Triassic sediments intruded by andesitic dikes and stocks

DETAILED STRATIGRAPHY

TRABUCO FORMATION

This formation, here tentatively called Cretaceous, forms the base of the unmetamorphosed sedimentary section of the northern Santa Ana Mountains from Blackstar Canyon south to the southern tip of the Cretaceous beds mapped. The formation was first distinguished as a separate stratigraphic unit by Packard (7, p. 140), who named it from Trabuco Canyon. It is a soft red deeply weathered massive conglomerate composed of an unsorted mass of cobbles including in its

composition metamorphosed sandstones, cherts, limestones, and slates, and abundant andesitic blocks with a small proportion of coarse-grained acidic plutonics, and varying in size from grits to boulders more than a foot in diameter. Short lenses of coarse cross-bedded arkosic sands are present. Except for these lenses, bedding is uncommon in the Trabuco and calculations of the attitude and thickness of the formation are difficult and unreliable. Assuming that the Trabuco has about the same strike and dip as the member overlying, the thickness is estimated to approximate 300–400 feet, but in the vicinity of Silverado Canyon it appears to exceed this amount. The conglomerate nearly everywhere is deeply weathered. The weathering commonly extends even to the centers of the more resistant boulders, tingeing them a brick red and decomposing them so that they crumble under slight stress. The andesites, and the metamorphosed sediments which form so large a proportion of the boulders of the conglomerate are very similar in character to the Triassic rocks and associated intrusives that compose the basement complex, from which they probably are derived. Other important rock types but sparingly represented in the Trabuco boulders include a variety of acid hypabyssal rocks, and a coarse-grained dioritic rock similar to a type found on the east side of Elsinore Valley, a few miles east of the Santa Ana Mountains.

The Trabuco formation lies on the basement with a profound unconformity, which is strikingly shown in many places. In the Silverado-Ladd canyons area, the basement rock is an andesite, which according to Moore (13, p. IV, 32) is intruded into Triassic slate. Three-quarters of a mile east of the Trabuco-andesite contact in the Ladd Canyon region, a considerable thickness of Cretaceous has been faulted down together with a mass of underlying basement. The basement rock here is Triassic slate dipping at a high angle to the northeast; the Trabuco lies above, in normal depositional contact, dipping at a high angle to the northwest. Near the Baker Canyon-Silverado Canyon divide, the plane of the basement-Trabuco contact cuts across the contact separating the andesites and metamorphics of the basement series. From this point north the Trabuco lies in normal depositional contact on the Triassic slates.

The Trabuco conglomerate is more readily eroded than is either the underlying basement or the overlying basal member of the Ladd formation. It thus forms a weak zone that has been excavated by small streams into a depressed strip bordered on the east by the higher steep erosion surface of the basement complex and on the west by the conglomerate cliffs of the Baker Canyon member.

LEGEND
EOCENE
Tmz
MARTINEZ FORMATION
UNCONFORMITY
UPPER CRE-TACEOUS
WILLIAMS FORMATION
UNCONFORMITY
LADD FORMATION
BAKER CANYON MEMBER
Kt
TRABUCO FORMATION
UNCONFORMITY
PRE-CRE-TACEOUS
BC
BASEMENT COMPLEX
CONTACTS
INTERFORMATIONAL
MEMBER OR LENS
FAULT
DIP AND STRIKE
FOSSIL LOCALITY
X 1057
A LINE OF COLUMNAR SECTION A'
SANTIAGO
CREEK
SIERRA
BLACK STAR
CREEK
Tmz
Kws
Kwp
Kln
Klb
Kt
BC
x 1093
x 1096
x 1168
x 1097
F'

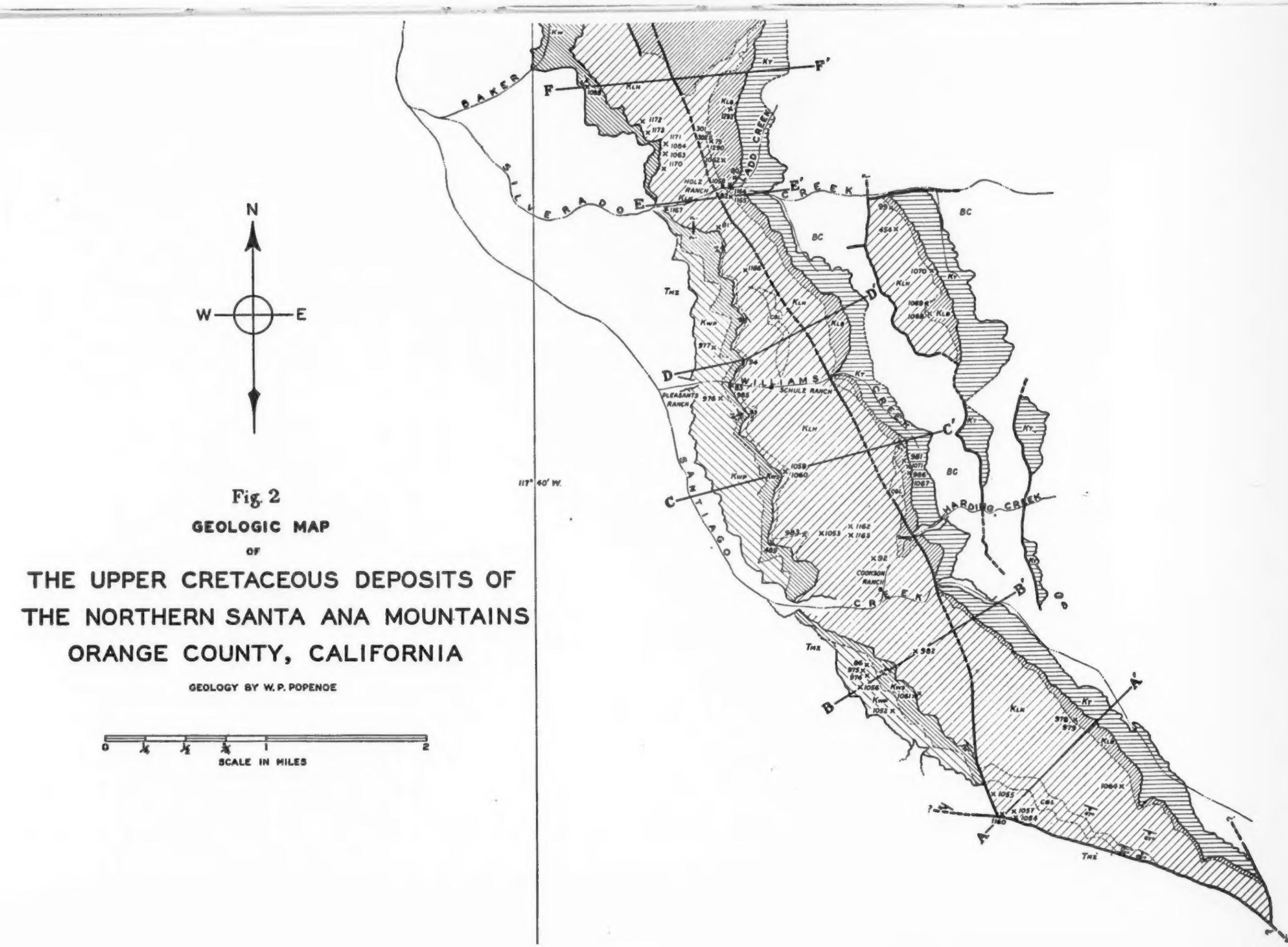


Fig. 2
GEOLOGIC MAP
OF
THE UPPER CRETACEOUS DEPOSITS OF
THE NORTHERN SANTA ANA MOUNTAINS
ORANGE COUNTY, CALIFORNIA
GEOLOGY BY W. P. POPENOE
N
W
E
0
1
2
SCALE IN MILES
117° 40' W.
BAKER
SILVERADO
CREEK
WILLIAMS
CREEK
SANTIAGO
CREEK
HARDING CREEK
HOLZ RANCH
SCHULZ RANCH
PLEASANTS RANCH
COOKSON RANCH
BC
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'

FIG. 2

The Trabuco conglomerate is unfossiliferous; and its precise age is unknown. Structurally it is closely related to the overlying marine early Upper Cretaceous beds, and probably is thus of early Upper or late Lower Cretaceous age.

LADD FORMATION

The Ladd formation includes those Cretaceous sediments of the Santa Ana Mountains lying stratigraphically above the red Trabuco conglomerate, and below the base of the Williams formation. The type locality of the formation is the region immediately west of the mouth of Ladd Canyon, a tributary of Silverado Canyon. The greatest measured thickness of the formation approximates 1,700 feet. The contact of the Ladd formation with the Trabuco formation below is probably conformable, and in places appears to be gradational; the contact with the Williams formation above is abrupt wherever it has been observed and is believed to be disconformable or perhaps unconformable. The Ladd formation is divisible into two members—the Baker Canyon member below, and the Holz shale above.

BAKER CANYON MEMBER[4]

This member, named for its great development in Baker Canyon, north of Silverado Canyon, includes the gray conglomerates and greenish gray to brown sandstones that immediately overlie the Trabuco formation and underlie the thick gray silty shales of the Holz shale member in the Santa Ana Mountains. The thickness of this member in the vicinity of Silverado Canyon approximates three hundred feet; in the vicinity of the type locality, and also in the Harding Canyon region, it is much thicker. The member is composed characteristically of coarse hard gray thick-bedded boulder conglomerate below grading up into thick-bedded to shaly, arkosic, gray-green, more or less calcareous sandstone above. The basal conglomerates meet the Trabuco conglomerate below with a contact generally abrupt, though in places it seems gradational. Compared with the Trabuco, the Baker Canyon conglomerates are better consolidated and bedded, show better sorting, perhaps smaller average boulder size, and are far less weathered, the boulders being in general fresh and hard. In composi-

[4] The name "Baker Canyon" seems preferable to the previously used name "Baker," as the latter has been used elsewhere by other authors in the description of other beds. The Baker Canyon member, here described from its occurrence in Baker Canyon, has been described previously as the "Baker member" and the "Baker conglomerate" in the following publications.

Willis Parkison Popenoe, "Upper Cretaceous Mollusca from Southern California," *Jour. Pal.*, Vol. 11, No. 5 (Tulsa, July, 1937), pp. 279–402.

———, "The Trabuco and Baker Conglomerates of the Santa Ana Mountains," *Jour. Geol.*, Vol. 49, No. 7 (Chicago, October–November, 1941), pp. 738–52.

tion, the two conglomerates are similar. The principal rock types are andesites and metamorphosed sediments. The relative proportions of these types are variable from place to place. Topographically, the Baker Canyon member crops out along a bold, bare, and steep cliff face overlooking the longitudinal valleys carved in the Trabuco formation, along most of its extent.

The conglomerates of the Baker Canyon member grade upward into and in places are interbedded with the sandstones that form the upper part of the member. These sandstones are typically coarse, hard, well cemented, massive, and highly arkosic near the transition into the conglomerates below but become progressively finer and more shaly toward the top of the member, where they grade into the Holz shale. Stringers and lenses of pebbles are found here and there interbedded with the sandstones, and some soft, thin-bedded, shaly and calcareous bands may alternate with the more massive phases. The sandstone varies considerably in thickness. Just north of Williams Canyon and just south of the forks of Santiago and Harding canyons, little sandstone is present, the transition from conglomerate to shale taking place within a stratigraphic interval of 50 feet or less. Conversely a mile or more south of the mouth of Harding Canyon a lens of sandstone several hundred feet thick is developed between the Baker Canyon conglomerate and the Holz shale. The lenticular character of this sandy phase suggests that some of the beds mapped as basal Holz shale are actually contemporaneous in deposition with beds mapped elsewhere as Baker Canyon sandstone. The transition from sandstone to shale is commonly gradual.

HOLZ SHALE

A thick shale series overlies the Baker Canyon member named the Holz shale from excellent exposures at the type locality, the Holz Ranch on the north side of Silverado Canyon just west of the mouth of Ladd Canyon. The Holz shale is the most persistent and thickest member of the Cretaceous sequence of the Santa Ana Mountains. It may be followed in virtually unbroken exposure from Santa Ana Canyon south to near Trabuco Canyon—a distance of 15 miles. Its thickness, which generally exceeds the combined thicknesses of the remaining members of the Cretaceous section of this region, approximates 1,500 feet in the vicinity of Williams and Harding canyons.

The predominant rock type of the Holz member is a soft, poorly bedded, brownish gray, micaceous, sandy shale, but variations from this lithology are numerous and extreme. Thin beds of concretionary limestone are common locally; persistent, though thin beds of gritty

sandstone are found in many places; and lenses of coarse conglomeratic sandstone and massive conglomerates are developed within the shale at many localities.

The contact of the Holz shale with the Baker Canyon member below is almost everywhere gradual, and in mapping has been arbitrarily placed at the lowest dominantly shaly beds in the section. Conversely, the contact of the Holz shale with the basal beds of the overlying Williams formation is commonly abrupt and is believed to represent a disconformity or slight unconformity.

The greatest measured thickness of the Holz member is found in the area between Harding and Williams canyons where a total of about 1,500 feet of shale is exposed. This figure does not represent the full thickness of the member, for here part of the section is cut out by a persistent longitudinal fault that involves the shale on one or both sides of its trace at least from Baker Canyon south to about one mile south of Harding Canyon, where the fault passes into the Tertiary beds. The total displacement of this fault is not known but certainly exceeds 150 feet. South of the point where this fault leaves the shale section, the Tertiary beds are dropped against the shale by an intersecting fault that has cut from the section south of this point the entire overlying Williams formation and in addition probably 500 feet of the top of the Holz shale as well.

The presence of conglomerate lenses in the shale has been mentioned. Many of these lenses are not more than a few feet in thickness and a few yards in length. Some of them, however, are huge. A conglomerate-sandstone lens about 3,000 feet long and perhaps 75 feet thick is developed in the midst of the shale section in the region between Williams and Silverado canyons. Many of the boulders in this lens exceed a foot in diameter. In the region near the mouth of Harding Canyon a thick conglomerate lens is found directly overlying the fossiliferous sandstones of the Baker Canyon member. The length of this lens exceeds a mile and its maximum measured thickness approximates 100 feet. In the region a mile or more south of Harding Canyon, a lens of coarse conglomerate and gritty sandstone is found well up in the shale section. Its thickness exceeds 300 feet, and its exposed length is more than a mile. Its original length was greater for it is truncated at both ends by faults. The most spectacular lens in the shale is developed in the basal part of the member. The southern end of this lens forms a high bluff about $\frac{3}{4}$ mile north of the Holz Ranch in Silverado Canyon. The lens is here approximately 600 feet thick, but apparently thickens somewhat to the north. Its length is more

than 3 miles. Throughout most of this distance, it merges below with the Baker member, and has been given the same symbol on the geologic map accompanying this report. The lens is composed of gritty feldspathic sandstone beds alternating with boulder beds carrying fragments ranging in size from small pebbles to great angular blocks 3 and 4 feet in diameter. In general, the mass is well consolidated.

A short distance south of the head of Black Star Creek, the entire basal series of the Cretaceous, including the Trabuco conglomerate, the Baker Canyon member, and the great conglomerate lens described above, pinches out and disappears. Near the head of Black Star Canyon, the Triassic slates and the Holz shale crop out within a few yards of one another, though no actual contact between the two is visible. From this point north to the north wall of Sierra Canyon, the shale appears to be in direct contact with the basement rock. North of Sierra Canyon, and extending nearly to Santa Ana Canyon—a distance of about a mile—soft reddish and brownish coarse boulder conglomerates appear above the Triassic with normal depositional contact, and apparently in fault contact with a thin strip of Holz shale above. This reddish conglomerate may represent the Trabuco formation or the Trabuco plus part of the Baker Canyon member.

The terrane underlain by the Holz shale weathers into smoothly rounded slopes characteristically mantled by low brush and grass. Good exposures are rather rare.

WILLIAMS FORMATION

This formation, named from characteristic exposures along Williams Canyon near its mouth, forms the summit of the Cretaceous section of the Santa Ana Mountains. At the type locality, the formation is approximately 500 feet thick. Its basal member—the Schulz conglomerate and sandstone—includes a succession of loosely consolidated boulder beds and coarse light-colored feldspathic sandstones. The upper part of the formation, here named the Pleasants sandstone, is finer-grained, non-conglomeratic calcareous sandstone. The rocks of the formation are prevailingly light-colored. Pinkish tints induced by limonite stain are characteristic. The outcrop of the formation is nearly everywhere mantled by a thick growth of stubborn and resistant brush that contrasts markedly with the smooth grass-covered slopes of the shales below.

SCHULZ MEMBER

The type locality of the Schulz member is approximately $\frac{1}{4}$ mile upstream from the mouth of Williams Canyon, near the west boundary

of the Schulz Ranch. The member is composed of coarse, light-colored, soft, cross-bedded, arkosic sandstone with subordinate boulder beds. The boulders in the conglomeratic phases are commonly of rather small size, individual fragments as large as a foot across being rare. The boulders are nearly all well rounded and fresh. In composition they range from cherts and quartzites to a variety of types of volcanic and plutonic rocks. Quartz pebbles are abundant. The coarse sandy matrix in which the boulders are embedded readily breaks down, and the conglomerates weather to subdued rounded ridges and slopes markedly different in appearance from the bold cliffs formed by the Baker member. The arkosic sandstones that form the upper part of the member form thick cream-colored to pink layers of soft rock that in the Black Star and Sierra Canyon regions crop out over large areas, capping the stream divides. In this region, the sandstones characteristically weather out on the surface in immense monolothic blocks that lie scattered about like so many Stonehenges.

The character of the Schulz conglomerate at its lower contact with the Holz shale varies greatly from place to place, but everywhere shows an abrupt change from the rock below. In the vicinity of Harding Canyon, little conglomerate is present in the member, the rock at the contact being a soft pebbly sandstone. In Williams Canyon, coarse conglomerates are found immediately above the contact with the shale. South of Silverado Canyon, soft silty sandstone beds immediately overlie the shales and are succeeded a short distance above by boulder beds. North of Silverado Canyon the basal beds of the Schulz member are coarsely conglomeratic. Along the west walls of Baker and Black Star canyons the Schulz member just above the contact is ordinarily a coarse sandstone, in places feldspathic, in places nearly pure olive-colored quartz sand. Fragments of shale resembling the Holz shale below are common in the lower few feet of sandstone above the contact. The single fossil occurrence listed from this member (C.I.T. loc. 1066) is in sandstone at the base of the member at the crest of the Baker Canyon-Black Star Canyon divide. This may represent reworked material from the Holz shale below. With this exception, no fossils have been found in the Schulz conglomerate.

The Schulz member averages approximately 200 feet in thickness in the southern part of the area mapped, but in the region north of Baker Canyon is probably somewhat thicker. In the northern region it shows a tendency toward cavernous weathering, and toward formation of joints perpendicular to the bedding planes, a characteristic that gives a fluted or columnar appearance to the bluff faces along which it crops out.

PLEASANTS SANDSTONE MEMBER

This member is named for the Pleasants Ranch at the mouth of Williams Canyon. It is composed chiefly of very fine-grained, light-colored, thin-bedded, ferruginous and micaceous shaly sandstones with which are interbedded numerous thick layers of cross-bedded calcareous sandstones or sandy limestones. These limy beds weather out on the surface of the outcrop as rusty red concretion-like blocks that in places carry well preserved fossils. The first appearance of these rusty limy blocks in ascending the section has been taken as the base of the member in mapping.

The Pleasants member is discontinuous in its distribution, as it is cut out of the section in many places by faulting and by overlap. From the southern tip of the area mapped to the region a mile and a half south of Harding Canyon, the entire Williams formation has been cut out by faulting. Near the mouth of Harding Canyon, the Pleasants sandstone is overlapped by the basal Tertiary beds, for a distance of about ½ mile. North of Silverado Canyon, the Pleasants member is again overlapped for a distance of approximately ¾ mile. From Baker Canyon north, the member is represented only in small discontinuous and isolated areas. With one or two exceptions it has not been differentiated on the map north of Silverado Canyon, from the underlying Schulz member.

Determination of the thickness of the members of the Williams formation is difficult, owing to the overlaps and faulting that have affected these members so widely. The most trustworthy calculation, based on measurements taken in the vicinity of the type locality, gives an approximate thickness of 200 feet for the Schulz member and 320 feet for the Pleasants member.

CRETACEOUS-TERTIARY CONTACT

The Tertiary beds immediately overlying the uppermost Cretaceous rocks in the northern Santa Ana Mountains are a series of loosely consolidated conglomerates, and coarse arkosic sandstones, with some clay and coal beds. They are of Martinez Eocene age as is indicated by the presence not far above the contact of *Turritella pachecoensis* and a few other characteristic Martinez marine species. Along most of the contact, the basal Martinez beds rest on some level of the Pleasants member of the Williams formation. Near the mouth of Harding Canyon, and north of Silverado Canyon, the Martinez overlaps the Pleasants member completely and rests on the Schulz conglomerate. Along the slope of the north wall of Sierra Canyon, beds of the Pleasants member, Schulz member, and Holz shale member may be

seen in succession from west to east dipping westward gently. The basal Martinez crops out along the top of the canyon wall overlapping in turn the Pleasants and Schulz members, and resting near the head of the canyon on the beveled strata of the Holz shale. A quarter mile south of this point, along the trail leading from the head of Black Star Canyon into Sierra Canyon, Martinez beds overlie the arkosic sandstones of the Schulz member.

CRETACEOUS STRATIGRAPHY OF SIMI HILLS

According to Kew (10, pp. 11–12) the Cretaceous sediments of the Simi Hills are divisible into two members. The lowest member consists of 250 feet of calcareous sandstone at the base and an equal thickness of gray shale above. The upper member, overlying the gray shale, consists of approximately 5,500 feet of alternating thick beds of massive brown sandstone and thin beds of shale. Later unpublished work suggests that the lower member is much thicker and more complex than Kew suggests; but the details are not yet available. The base of the Cretaceous in this region is overlapped by Miocene sandstone. All the fossils so far recovered from this region are from the calcareous sandstones of the lower member.

CRETACEOUS STRATIGRAPHY OF SANTA MONICA MOUNTAINS

Recent work by H. D. B. Wilson of the California Institute of Technology has shown that the Cretaceous beds east of Topanga Canyon in the Santa Monica Mountains may be divided into five members. In ascending order, these are as follows.

1. Soft red unsorted unfossiliferous boulder and cobble conglomerate, similar to the Trabuco formation of the Santa Ana Mountains. Unconformably overlies the Santa Monica slate. Maximum thickness, 750 feet
2. Brown coarse unfossiliferous (?) thick-bedded arkose. Maximum thickness, 2,500 feet. Unconformable on member 1 above
3. Massive fresh unfossiliferous cobble conglomerate. Maximum thickness, probably 3,500–4,000 feet. Conformable with member below and above
4. Hard fine-grained and more or less well bedded fossiliferous sandstones. Fossils fairly abundant in lenses in the lower 100 feet. Maximum thickness, 300 feet more or less. Conformable with member above and below
5. Coarse brown unfossiliferous arkose similar to member 2 above. Maximum exposed thickness, 1,000 feet. Overlapped by Tertiary beds

All of the determinable fossils collected in this region are from member 4.

UPPER CRETACEOUS FAUNAS OF SOUTHERN CALIFORNIA

The faunal check list accompanying this report (Fig. 4) lists 87 species of mollusks from the Santa Ana Mountains, the Simi Hills, and the Santa Monica Mountains. Excepting the fauna from the

Fig. 3

GENERALIZED COLUMNAR SECTIONS OF THE UPPER CRETACEOUS OF THE SANTA ANA MOUNTAINS

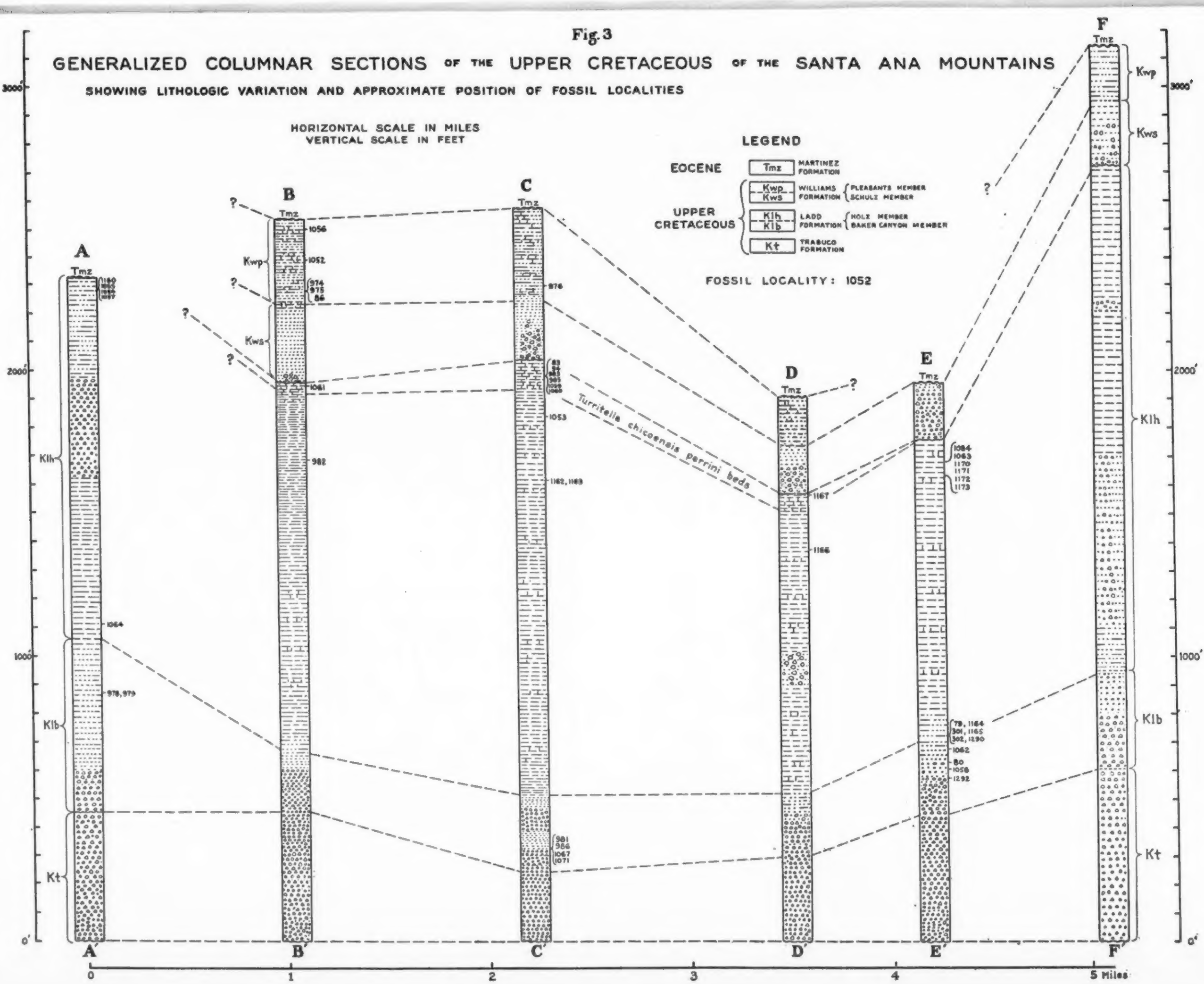
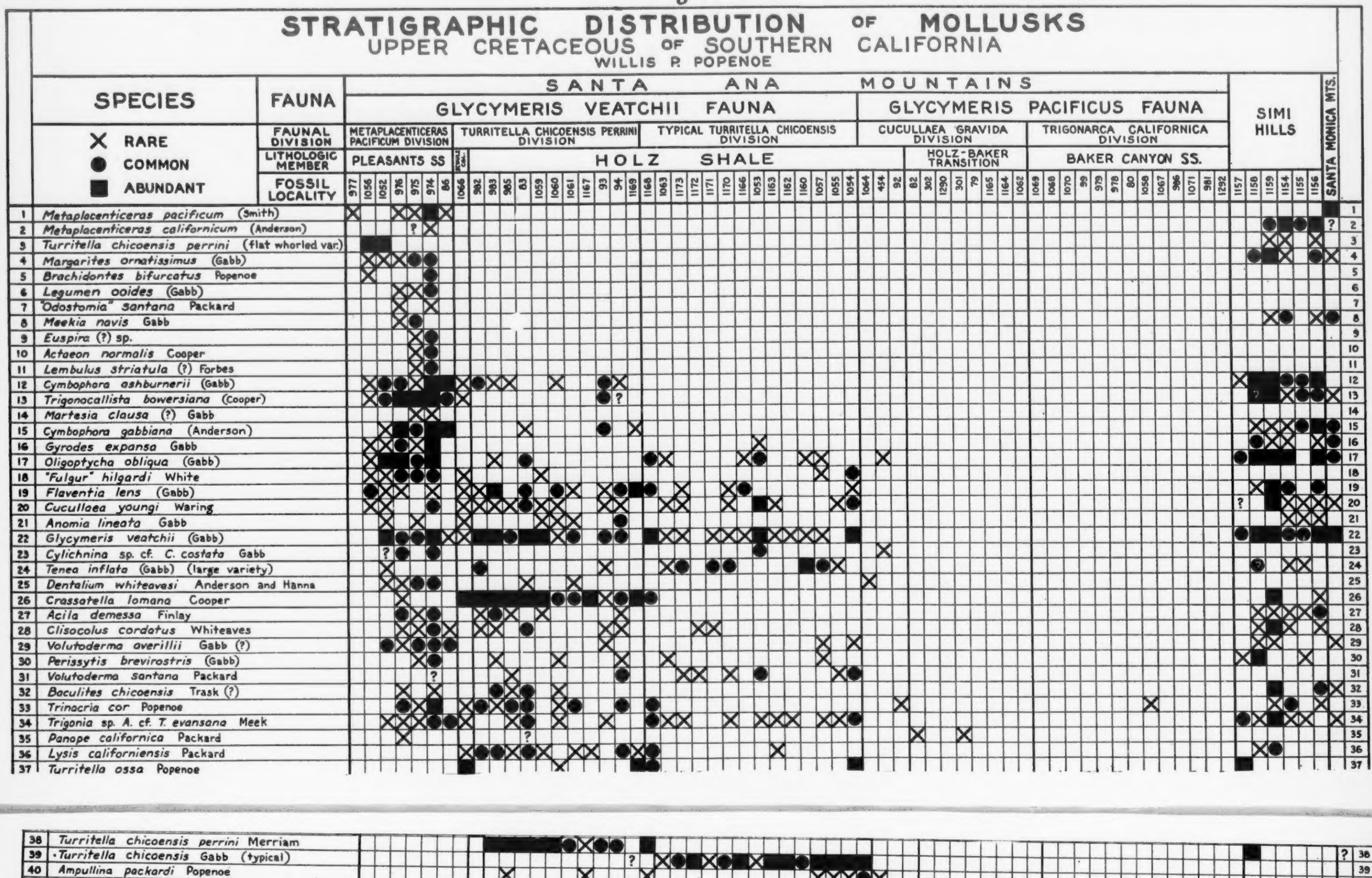


Fig. 3
GENERALIZED COLUMNAR SECTIONS OF THE UPPER CRETACEOUS OF THE SANTA ANA MOUNTAINS
SHOWING LITHOLOGIC VARIATION AND APPROXIMATE POSITION OF FOSSIL LOCALITIES
HORIZONTAL SCALE IN MILES
VERTICAL SCALE IN FEET
LEGEND
EOCENE
Tmz MARTINEZ FORMATION
UPPER CRETACEOUS
Kwp Kws WILLIAMS FORMATION PLEASANTS MEMBER SCHULZ MEMBER
Klh Klb LADD FORMATION HOLZ MEMBER BAKER CANYON MEMBER
Kt TRABUCO FORMATION
FOSSIL LOCALITY: 1052
Turritella chicoensis perrini beds
A B C D E F
A' B' C' D' E' F'
0 1 2 3 4 5 Miles
0' 1000' 2000' 3000'

FIG. 3

Fig. 4



STRATIGRAPHIC DISTRIBUTION OF MOLLUSKS
UPPER CRETACEOUS OF SOUTHERN CALIFORNIA
WILLIS P. POPENOE
SPECIES
X RARE
● COMMON
■ ABUNDANT
FAUNA
FAUNAL DIVISION
LITHOLOGIC MEMBER
FOSSIL LOCALITY
SANTA ANA MOUNTAINS
GLYCYMERIS VEATCHII FAUNA
GLYCYMERIS PACIFICUS FAUNA
METAPLACENTICERAS PACIFICUM DIVISION
TURRITELLA CHICOENSIS PERRINI DIVISION
TYPICAL TURRITELLA CHICOENSIS DIVISION
CUCULLAEA GRAVIDA DIVISION
TRIGONARCA CALIFORNICA DIVISION
PLEASANTS SS
HOLZ SHALE
HOLZ-BAKER TRANSITION
BAKER CANYON SS.
SIMI HILLS
SANTA MONICA MTS.
977 1056 1052 976 975 974 86 1066 982 983 985 83 1059 1060 1061 1167 93 94 1169 1168 1063 1173 1172 1171 1170 1166 1053 1163 1162 1160 1057 1055 1054 1064 454 92 82 302 1290 301 79 1165 1164 1062 1069 1068 1070 99 979 978 80 1058 1067 986 1071 981 1292 1157 1158 1159 1154 1155 1156
1 Metaplacenticeras pacificum (Smith)
2 Metaplacenticeras californicum (Anderson)
3 Turritella chicoensis perrini (flat whorled var.)
4 Margarites ornatissimus (Gabb)
5 Brachidontes bifurcatus Popenoe
6 Legumen ooides (Gabb)
7 "Odostomia" santana Packard
8 Meekia navis Gabb
9 Euspira (?) sp.
10 Actaeon normalis Cooper
11 Lembulus striatula (?) Forbes
12 Cymbophora ashburnerii (Gabb)
13 Trigonocallista bowersiana (Cooper)
14 Martesia clausa (?) Gabb
15 Cymbophora gabbiana (Anderson)
16 Gyrodes expansa Gabb
17 Oligoptycha obliqua (Gabb)
18 "Fulgur" hilgardi White
19 Flaventia lens (Gabb)
20 Cucullaea youngi Waring
21 Anomia lineata Gabb
22 Glycymeris veatchii (Gabb)
23 Cylichnina sp. cf. C. costata Gabb
24 Tenea inflata (Gabb) (large variety)
25 Dentalium whiteavesi Anderson and Hanna
26 Crassatella lomana Cooper
27 Acila demessa Finlay
28 Clisocolus cordatus Whiteaves
29 Volutoderma averillii Gabb (?)
30 Perissytis brevirostris (Gabb)
31 Volutoderma santana Packard
32 Baculites chicoensis Trask (?)
33 Trinacria cor Popenoe
34 Trigonia sp. A cf. T. evansana Meek
35 Panope californica Packard
36 Lysis californiensis Packard
37 Turritella ossa Popenoe
38 Turritella chicoensis perrini Merriam
39 Turritella chicoensis Gabb (typical)
40 Ampullina packardi Popenoe

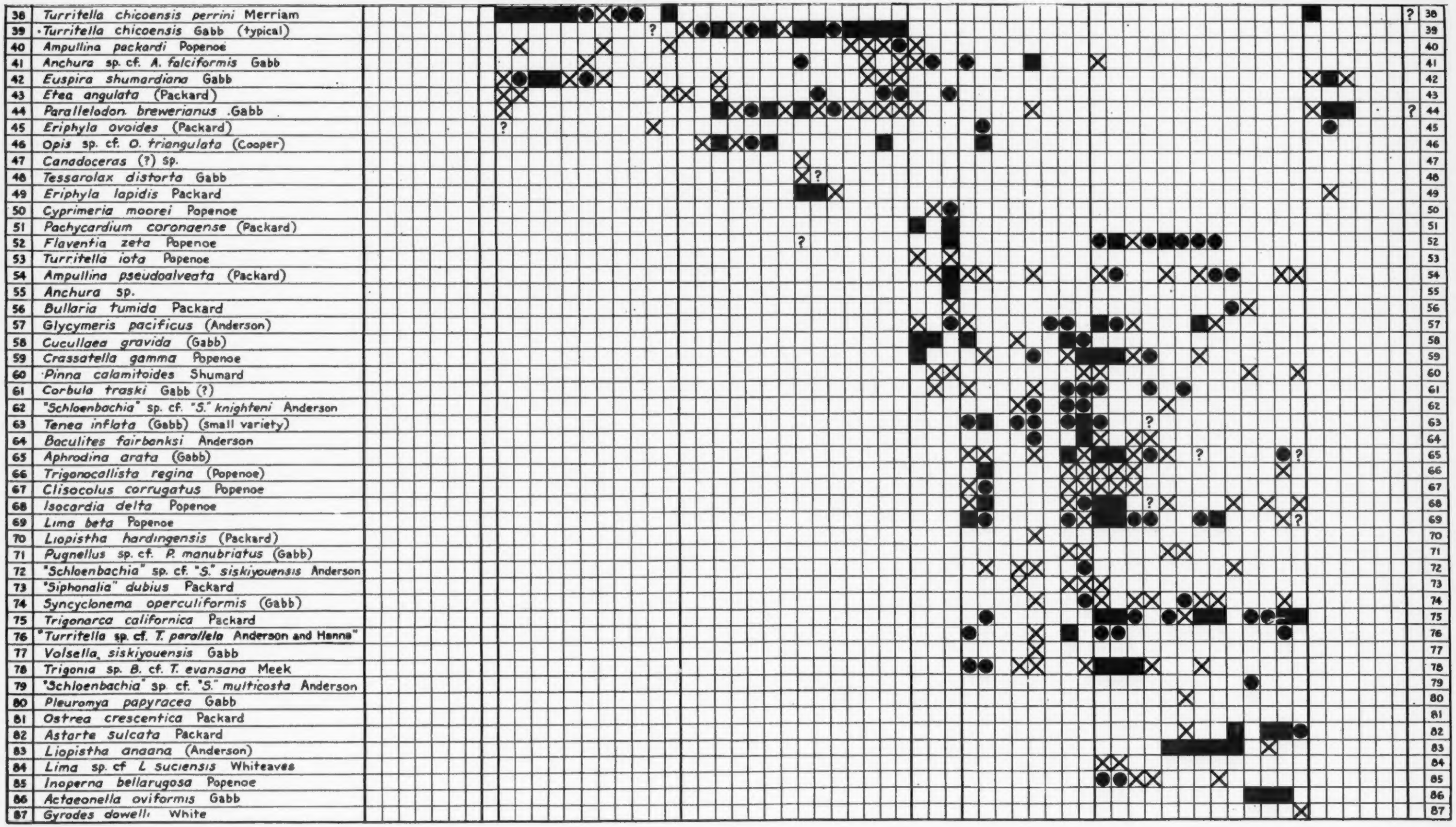


FIG. 4.—Errata: Species 30 should be *Perissitys breviostris* (Gabb); species 86 should be *Acteonella oviformis* Gabb.

Santa Monica Mountains, the presence and relative abundance of each species in each locality is indicated in the check list. Species represented in any locality by fewer than four specimens are listed as "rare"; forms represented by from four to twenty specimens are considered "common"; forms represented by more than twenty specimens from any one locality are considered "abundant". The fossil localities in the Santa Ana Mountains are listed on the geologic map and on the check list by the locality numbers of the California Institute of Technology invertebrate fossil locality catalog. These localities are arranged on the check list in descending stratigraphic order from left to right. The fossil localities of the Simi Hills are described in detail at the end of this paper. All collections with locality numbers lower than 900 were collected by B. N. Moore; those with locality numbers greater than 900 were collected by the writer.

The faunal list given is incomplete. It includes only those forms which, because of abundance, known geologic range, and distribution, seem of most value for the purposes of this report. For this reason the following have in most cases been omitted from the check list: the undescribed forms of the region; most of the species of unique or rare known occurrence; specifically indeterminate or doubtfully determinate forms; those of uncertain stratigraphic position; and those known only from faunal lists of other workers. The number of species listed might well be doubled were all of the forms that fall in the above categories to be included. It is planned to treat these excluded species in separate articles.

All of the fossil material on which this report is based is contained in the invertebrate fossil collections of the California Institute of Technology.

CRETACEOUS FAUNA OF SANTA ANA MOUNTAINS

The Cretaceous molluscan fauna of the Santa Ana Mountains appears naturally divisible into two major units which have comparatively few species in common. These units are here called, in ascending sequence, the *Glycymeris pacificus* fauna, and the *Glycymeris veatchii* fauna, after two abundant characteristic pelecypod species. The *Glycymeris pacificus* fauna is further divisible into two lesser and less well defined units of which the lower is called the *Trigonarca californica* division, the upper, the *Cucullaea gravida* division. The *Glycymeris veatchii* fauna is similarly divisible into three divisions. These are, from bottom to top, the *Turritella chicoensis* (typical) division, the *Turritella chicoensis perrini* division, and the *Metaplacenticeras pacificum* division. The fauna content and comparative stratigraphic positions of these divisions are shown on the check list.

The units set up here differ somewhat in their scope from those proposed by Packard (7, pp. 143–149) as a result of his study of the fauna of the region. Consequently new informal division names have been used. A more formal stage and zonal classification will not be proposed until determination of the ranges and associations of species in a number of other Cretaceous sections in the Pacific Coast region permits the establishment of better controls. It is not yet possible to say how far the "faunas" and "divisions" described here may be recognized beyond the Santa Ana Mountains region. Nevertheless, there is considerable evidence that distinct assemblages corresponding closely to the *Glycymeris pacificus* and *Glycymeris veatchii* faunas and in the same relative stratigraphic positions, may be recognized in the Upper Cretaceous of the San Joaquin Valley, and the upper Sacramento Valley of California, and in southern Oregon.

The differences among the "divisions" may possibly be more local in character than the differences among the "faunas" and for that reason they must be used with considerable caution in making correlations beyond the southern California region. They have as yet not been definitely recognized beyond the limits of the Santa Ana Mountains, though there is a suggestion that some of them may be delimited more or less precisely in the Simi Hills and the Santa Monica Mountains as well.

The influence of facies control in bringing about the faunal changes here observed is at present difficult to evaluate. Facies influences are suggested in the fairly close correlation between lithologic and faunal changes in some parts of the Santa Ana Mountains section. At the same time the faunal succession in the Simi Hills, as far as known now, corresponds in general with a part of the Santa Ana Mountains succession, although the lithologic succession in the Simi Hills is different. In the present state of knowledge of Pacific Coast Upper Cretaceous stratigraphy and paleontology, however, it is idle to make any immediate attempt to separate facies factors from evolutionary factors in interpreting any observed succession. The following discussion is made with a full recognition of this condition.

Glycymeris pacificus FAUNA

The *Glycymeris pacificus* fauna ranges through the Baker Canyon sandstone member, the transitional shaly sandstone beds along the contact between the Baker Canyon member and the Holz shale, and is sparingly represented in the lower 200 feet of the Holz shale. This fauna includes about forty of the species tabulated in the check list, and has furnished by far the majority of the new species described from the Santa Ana Mountains. Many of the forms in this fauna

known from elsewhere in the California Cretaceous are included in W. M. Gabb's fauna from Cottonwood Creek, Shasta County, California, and in collections now at the California Institute of Technology from beds in the lower part of the Cretaceous section in the Redding district in the northern Sacramento Valley; in southern Oregon; and in the Coalinga region, San Joaquin Valley. These occurrences suggest a widespread distribution of this fauna in the early Upper Cretaceous of the Pacific Coast.

A considerable number of species range throughout this fauna. These include, among the more abundant forms, *Flaventia zeta*, *Ampullina pseudoalveata*, *Glycymeris pacificus*, *Crassatella gamma*, *Pinna calamitoides*, *Aphrodina arata*, *Trigonocallista regina*, *Lima beta*, *Isocardia delta*, and some other forms named in the check list. These species, together with the bulk of the remaining species of the fauna, are not found in the *Glycymeris veatchii* fauna above. It is possible, on the basis of the occurrence of a few species of restricted range, and on the common occurrence of species of overlapping ranges, to differentiate the faunal sub-groups of the *Trigonarca californica* and *Cucullaea gravida* divisions.

Trigonarca californica DIVISION

This division includes essentially the fauna of the Baker Canyon sandstone. Besides the species listed in the preceding paragraph the fauna of this division is characterized by the presence of a few distinctive forms that appear to be restricted to it. These include *Acteonella oviformis*, *Astarte sulcata*, *Liopistha anaana*, *Inoperna bellarugosa*, and the small ammonite "*Schloenbachia*" cf. "*S.*" *multicosta*. *Trigonarca californica* is probably the most distinctive single species found in the division, as it is more abundant and widely distributed than any other; in one locality, however, it has been found in the division overlying in company with the typical fossil of that division—*Cucullaea gravida*.

Cucullaea gravida DIVISION

The *Cucullaea gravida* faunal division ranges through the shaly sandstones at the Baker Canyon member-Holz shale contact, and up into the lower 200 feet of the typical Holz shale. The division is particularly characterized by the presence in abundance of *Cucullaea gravida* and of two fairly abundant keeled ammonites, "*Schloenbachia*" sp. cf. "*S.*" *siskiyouense*, and "*Schloenbachia*" sp. cf. "*S.*" *knighteni*, both of which however are sparingly represented in the division below. In addition, a number of species that are common in the earlier *Glycymeris veatchii* fauna make their first appearance in this division. These include *Parallelodon brewerianus*, *Opis* sp. cf. *O. triangulata*, *Etea angulata*, and *Anchura* sp. cf. *A. falciformis*.

The fauna of this division is much more localized in its distribution than is the fauna of the *Trigonarca californica* division. The region on both sides of Silverado Canyon in the vicinity of the Holz Ranch has furnished by far the greatest number of forms of this assemblage. A few localities yielding the characteristic association of species of this division have been found as far south as Harding Canyon, however.

Glycymeris veatchii FAUNA

The lower half of the Holz shale is barren above the basal beds that carry the *Cucullaea gravida* fauna. The upper half of the member, and the overlying Pleasants sandstones bear an abundant and distinct fauna. One of the most prevalent forms in this fauna is *Glycymeris veatchii* Gabb, which is taken as the typical fossil. Other abundant species that range throughout the fauna include *Perissitys brevirostris, Cucullaea youngi, Flaventia lens*, and *Turritella chicoensis* and its variants. On the basis of locally short-ranging species, and some other faunal peculiarities, the *Glycymeris veatchii* fauna may be subdivided into the *Turritella chicoensis* (typical) division, the *Turritella chicoensis perrini* division, and the *Metaplacenticeras pacificum* division, taken in ascending order.

Turritella chicoensis (TYPICAL) DIVISION

The fauna of this division ranges from approximately the middle of the Holz shale member to a horizon 200 feet below the top of the member. The fossils occur generally in sandy and calcareous beds and lenses in the shale, and more rarely in the shale itself. Typical *Turritella chicoensis* is one of the most abundant and characteristic species of this division, and is found in nearly all of the collections taken in the stratigraphic interval mentioned. *Eriphyla lapidis* appears to be restricted to this division, and *Opis* sp. cf. *O. triangulata* does not range higher. On the other hand, many forms that are abundant in the two higher divisions of the fauna first appear in the *Turritella chicoensis* beds.

Turritella chicoensis perrini DIVISION

This division ranges throughout a stratigraphic interval of about 200 feet at the summit of the Holz shale member. The beds in which the faunal group is developed are more sandy and calcareous than are the shales below, and the included fossils are characterized particularly by the giant size of many of the individuals and the massive character of most of the shells. Most of the species that first appear in the typical *Turritella chicoensis* beds below range up into this division, and a number of these species appear no higher. Among the latter are *Lysis californiensis, Turritella ossa, Euspira shumardiana*, and *Etea angulata. Turritella chicoensis perrini* appears to be restricted to the

division, and the following species make their appearance here: *Cymbophora gabbiana*, *Cymbophora ashburnerii*, *Trigonocallista bowersiana*, *Acila demessa* and *Baculites chicoensis?* The fauna of the division thus reflects a strong probable facies influence but at the same time includes a unique association of species.

Metaplacenticeras pacificum DIVISION

The fauna of this division is found in calcareous sandstone blocks interbedded with the light-colored silty sandstones of the Pleasants member of the Williams formation. The division thus represents the youngest Cretaceous fauna in the northern Santa Ana Mountains.

The Pleasants sandstone has yielded fossils throughout its extent, though in most places these are poorly preserved. The best collections were made south of Harding Canyon near the Santiago-Aliso Creek divide. Additional good material has been collected from the type locality of the Pleasants member.

Thirty-five species of mollusks from this division are named in the check list. Of these, about a dozen species have not been found lower. These restricted forms include *Metaplacenticeras pacificum* which is found widely distributed in an apparently restricted stratigraphic band in the Pacific Coast Cretaceous. Other abundant and widely distributed restricted species include *Margarites ornatissimus* and *Legumen ooides*.

CRETACEOUS FAUNAS OF SANTA MONICA MOUNTAINS

The fauna from the Santa Monica Mountains Cretaceous as given in the check list is essentially a composite of collections made by H. W. Hoots, W. P. Woodring, and the writer. The stratigraphic work of H. D. Bruce Wilson of the California Institute of Technology has shown that these collections all come from a single member and stratigraphic level near the top of the exposed Cretaceous section of this region. An analysis of the faunas from the separate localities shows that they are essentially uniform in composition.

A number of species listed in Hoots' report on the Santa Monica Mountains have not been recognized elsewhere, and are not included in the check list accompanying the present paper. Most of these species are specifically indeterminate or undetermined and are for that reason of small significance in the present discussion. These species include:

Incceramus sp.
Pholadomya sp.
Crassatella sp. A
Crassatella sp. B
Protocardia sp.
Corbula sp.
Conchothyra rotunda? (Waring)
Eutrephoceras sp.
Baculites sp.
"*Pachydiscus*" sp. A
"*Pachydiscus*" sp. B
"*Pachydiscus*" sp. C

Those species in the check list that are common to the Santa Monica Mountains and Santa Ana Mountains localities, with the exception of the questionably determined *Parallelodon brewerianus*, are all found in the *Metaplacenticeras pacificum* division of the Santa Ana Mountains. A number of these species are not found lower in the Santa Ana Mountains section. The *Metaplacenticeras*-bearing sandstone of the Santa Monica Mountains is thus a very close correlative of the Pleasants sandstone. The great thickness of section underlying the *Metaplacenticeras* beds in the Santa Monica Mountains has so far yielded no diagnostic fossils and it is uncertain therefore except in a very general way how it may be correlated with the lower part of the Santa Ana Mountains section.

CRETACEOUS FAUNAS OF SIMI HILLS

The stratigraphic relationships of the Simi Hills Cretaceous fossil localities to one another are approximately as follows: localities 1154, 1155, and 1156 are nearly at the top of the calcareous sandstones that form the lower half of Kew's lower member in Dayton Canyon. These localities represent essentially the same stratigraphic level and are the youngest Cretaceous faunas collected in this region so far. Locality 1159 is in the same area but is perhaps 150 or 200 feet lower stratigraphically than the three localities aforementioned. Localities 1157 and 1158 are one mile east of the Dayton Canyon localities, on the north side of Bell Canyon, Calabasas Quadrangle, Ventura County. The region between Bell and Dayton canyons is badly faulted and in a difficult terrane, so that the actual stratigraphic relationships of these regions to one another have not been worked out. There is reason to believe that the Bell Canyon faunas are older than are those from Dayton Canyon; but evidence for this is as yet inconclusive.

Comparison of the fossil lists from the Simi Hills with those of the Santa Ana Mountains makes these relationships at once apparent: none of the characteristic species of *Glycymeris pacificus* fauna is present in the Simi Hills collections; similarly such species as *Etea angulata, Opis* sp. cf. *O. triangulata,* typical *Turritella chicoensis,* and *Tenea inflata,* that especially characterize the *Turritella chicoensis* division, are absent from the Simi Hills collections. Localities 1157 and 1158 yield several species such as *Turritella chicoensis perrini* (typical), *Eriphyla lapidis, E. ovoides, Lysis californiensis?, Parallelodon brewerianus, Ampullina packardi, et cetera.* This association is limited to the *Turritella chicoensis perrini* division in the Santa Ana Mountains. Locality 1159 yields a fauna with numerous *Metaplacenticeras* together with a few species that have not been found with this ammonite genus elsewhere, but commonly range lower in the section. Localities

1154, 1155, and 1156 all contain abundant *Metaplacenticeras* in association with a group of pelecypod and gastropod species characteristic of the *Metaplacenticeras pacificum* division of the Santa Ana Mountains and of the correlative *Metaplacenticeras* beds of the Santa Monica Mountains.

TENTATIVE CORRELATION OF UPPER CRETACEOUS OF SOUTHERN CALIFORNIA

On the basis of evidence presented here, this tentative correlation is offered for the Upper Cretaceous of southern California: the *Metaplacenticeras*-bearing sandstones near the top of the Cretaceous section of the Santa Monica Mountains, and Simi Hills localities 1154, 1155, 1156, and probably 1159, are approximate correlatives of the Pleasants sandstone, or beds carrying the *Metaplacenticeras pacificum* faunal division, in the Santa Ana Mountains. Localities 1157 and 1158 of the Simi Hills appear to represent a horizon approximately equivalent to the *Turritella chicoensis perrini* division of the Santa Ana Mountains, and can not certainly be considered older. The equivalent of this horizon in the Santa Monica Mountains can not now be delimited. The coarse unfossiliferous sandstones at the top of the section in the Simi Hills appear to be younger than any rocks exposed in the Santa Ana Mountains Cretaceous, but may be in some part equivalent to the 1,000 feet of arkose overlying the *Metaplacenticeras* beds in the Santa Monica Mountains. The thick section of arkose and conglomerate underlying the *Metaplacenticeras* beds of the Santa Monica Mountains is probably correlative at least in some part with the Ladd formation of the Santa Ana Mountains but detailed correlation is at present impossible.

CALIFORNIA INSTITUTE OF TECHNOLOGY CRETACEOUS LOCALITIES IN SIMI HILLS

1154 Simi Hills, Ventura Co., Calif., S.E. side of the Simi Hills on the Ventura-Los Angeles Co., line on spur between north and south branches of Dayton Canyon, 3,150 feet N. 76° W. of the S.E. corner of Sec. 28, T. 2 N., R. 17 W., and 200 feet more or less above the canyon floor. Calabasas Quadrangle.

1155 Limy sandstone beds in sandy shales, south side of south fork of Dayton Canyon, 3,850 feet S. 81° W. of the S.E. corner of Sec. 28, T. 2 N., R. 17 W., Calabasas Quadrangle, Ventura County.

1156 Sandstones cropping out on ridge crest about 300 feet S.W. of locality 1155. S.E. slope of Simi Hills, Calabasas Quadrangle, Ventura County, California.

1157 Simi Hills, north bank of Bell Canyon in shale of bluffs above stream channel, about 59 feet below base of massive Cretaceous sandstone, 1 mile straight west of the Los Angeles-Ventura County line on the boundary (extended) between Ts. 1 and 2, Calabasas Quadrangle, Ventura County, California.

1158 S.E. slope of Simi Hills, about 1.15 miles due west of Los Angeles-Ventura County line on the boundary (extended) between T. 1 N., and T. 2 N., Calabasas Quadrangle, Ventura County, California. Approximately same horizon as loc. 1157.

1159 Prominent fossil bed on crest of spur between forks of Dayton Canyon, about 400 feet east of the Los Angeles-Ventura County line, and 6,000 feet N. 23° W. of the S.E. corner of Sec. 33, T. 2 N., R. 17° W., Calabasas Quadrangle, Los Angeles County, California.

BIBLIOGRAPHY

1. GOODYEAR, W. A. *California State Min. Bur. 8th Ann. Rept. State Mineralogist* (1888), pp. 337-38.
2. FAIRBANKS, H. W. *Ibid., 11th Ann. Rept. State Mineralogist* (1892), pp. 115-18.
3. COOPER, J. G. *Ibid., Bull. 4*, No. 4 (1894), pp. 34-35 *et seq.*
4. SMITH, J. P., "The Phylogeny and Development of *Placenticeras*," *Proc. California Acad. Sci.* (3), Vol. 1, No. 7 (1900), p. 210.
5. ANDERSON, F. M., "Cretaceous Deposits of the Pacific Coast," *ibid.*, Vol. 2, No. 1 (1902).
6. PACKARD, E. L. *Univ. California Bull. Dept. Geol.*, Vol. 8, No. 11 (1914), pp. 262-63.
7. ———. *Ibid.*, Vol. 9, No. 12 (1916), pp. 137-59.
8. WARING, C. A. *Proc. California Acad. Sci.* (4), Vol. 7, No. 4 (1917).
9. PACKARD, E. L. *Univ. California Bull. Dept. Geol. Sci.*, Vol. 13, No. 10 (1922), pp. 413-62.
10. KEW, W. S. W. *U. S. Geol. Survey Bull. 753* (1924), pp. 11-13.
11. ENGLISH, W. A. *Ibid., Bull. 768* (1926), pp. 17-19.
12. HOOTS, H. W. *U. S. Geol. Survey Prof. Paper 165-C* (1930), pp. 90-93.
13. MOORE, B. N. *California Inst. Tech. Ph. D. Thesis* (1930).
14. POPENOE, W. P. *Jour. Paleontology*, Vol. 11, No. 5 (July, 1937), pp. 379-402.

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VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 188-196, 6 FIGS.

GEOLOGY OF DEL VALLE OIL FIELD, LOS ANGELES COUNTY, CALIFORNIA[1]

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ABSTRACT

R. E. Havenstrite's Lincoln well No. 1 was the discovery well of the Del Valle oil field. Oil has been produced at the Jasper Petroleum Company's Videgain well No. 1, 8,000 feet west of R. E. Havenstrite's Lincoln well No. 1. Future development may be expected to join these two areas of production. The structural trap may be controlled on the north by a south-dipping fault, and on the east and south by the easterly and southerly plunge of the folded sediments. The trap on the west side of the field is obscured by a south-dipping fault. Lenticular oil sands, or minor faulting, may form the trap on the west side of the field.

LOCATION

The Del Valle oil field is in the west part of Los Angeles County, 40 miles northwest of Los Angeles City and 4 miles west of Castaic Junction on the north side of Santa Clara River. Other oil fields in this

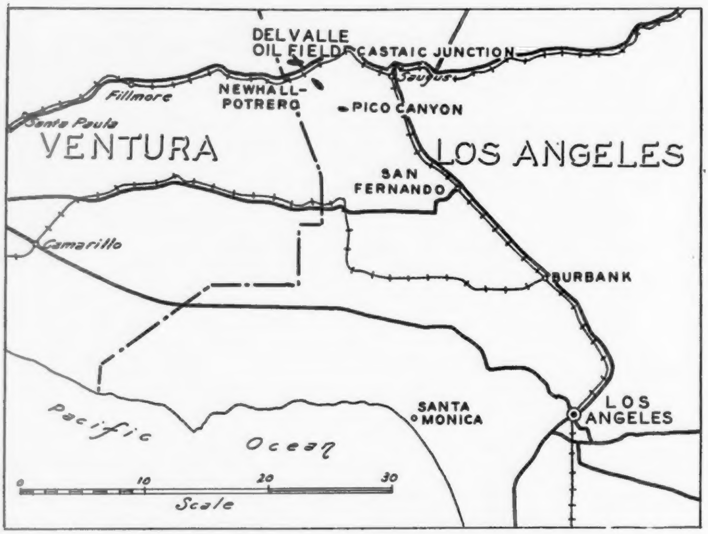

FIG. 1.—Sketch showing location of Del Valle oil field.

vicinity include the Pico Canyon oil field $4\frac{1}{2}$ miles southwest, the Newhall-Potrero oil field 2 miles southwest, and the Oak Canyon oil field 4 miles northwest (Fig. 1).

[1] Presented before the Pacific Section of the Association, at Los Angeles, October 17, 1941. Manuscript received, November 13, 1941.

[2] Standard Oil Company of California.

STRATIGRAPHY

General statement.—The sediments penetrated in the present development of the Del Valle oil field include the upper Modelo formation (upper Miocene), Pico formation (Pliocene), and Saugus formation (upper Pliocene and/or Pleistocene). The sediments exposed on the surface are limited to the middle and upper Pico and the Saugus formations. The surface study of the lower Pico and upper Modelo formations is best made on the Temescal anticline 4 miles northwest or on the Pico anticline 4 miles southeast.

Miocene-Modelo.—The upper lithologic member of the Modelo formation on the Temescal anticline comprises about 1,300 feet of interbedded gray and brown silty shale and sandstone with lenticular rusty brown pebble and cobble conglomerate. The lower part of this member varies from well bedded and laminated brown shale and gray sandstone with a few calcareous-cemented beds to rather massive gray and brown silty shale and sandstone. The upper part of this member varies from well bedded gray and brown silty shale and gray sandstone to massive gray and brown sandy siltstone and gray sandstone. Very lenticular sandy conglomerate strata are present throughout the member, but they are more numerous in the upper and middle parts. Lenticular oil saturation is present in the sandstone and conglomerate strata of this member on the south flank of the Temescal anticline. The lowermost part of this lithologic member is in the Mohnian paleontologic time stage, and the upper part is in the Delmontian stage, as defined by R. M. Kleinpell. The division between the Mohnian and Delmontian stages does not appear to be mappable in the field.

The Miocene sediments penetrated in the Del Valle oil field are in the upper lithologic member of the Modelo formation on the Temescal anticline. Sediments of Mohnian age have been penetrated but the present production is limited to the sediments of Delmontian age.

Pliocene-Miocene contact.—A study of foraminiferal samples indicates that a slight angular unconformity and overlap mapped on the east plunge of the Temescal anticline is equivalent to the Pliocene-Miocene foraminiferal division used in the Del Valle and Newhall-Potrero oil fields and the Pliocene-Miocene contact at the type section of the Modelo formation. Foraminiferal data in the Del Valle and Newhall-Potrero oil fields indicate that this unconformity, if present in these fields, is not sufficient to alter greatly the Modelo structure as interpreted from the overlying Pliocene sediments, although care should be used in applying this statement to any adjoining area.

Pliocene-Pico formation.—The Pliocene series includes the Pico

formation and part of the Saugus formation. The Pico formation may be divided into an upper and a lower member. The lower member is a sediment deposited in comparatively deep water analogous to the Repetto formation of the Los Angeles basin of deposition. It is often referred to as Repetto for this reason. The lower Pico sediments are composed of massive and bedded sandstone and gray, brown, and black siltstone similar to the uppermost sediment of the Modelo formation. Upward, the sediments gradually change to the gray siltstone, sandy siltstone, and sandstone of the upper Pico, and abruptly into the conglomeratic sandstone of the uppermost Pico.

The lower and upper members of the Pico formation are not mappable field units, for, although their lithologic and paleontologic characteristics are different, the change is gradational. The entire Pico formation has a rather uniform thickness in the Del Valle and Newhall-Potrero areas, but the lower Pico is about 3,200 feet thick in the Newhall-Potrero area and about 2,150 feet thick in the Del Valle area, whereas the upper Pico is about 3,200 feet thick in the Newhall-Potrero area and about 4,100 feet thick in the Del Valle area. The strata of the Pico formation are very lenticular and no individual beds can be traced far laterally. Oil-saturated sandstones have not been found in the outcrops of the Pico formation, excepting one isolated outcrop which may be associated with faulting.

Saugus formation.—There is some question about the correct position of the boundary between the Saugus and Pico formations in the Del Valle area. South of Santa Clara River the division has been placed at a local unconformity between marine strata and the overlying coarse-grained sediments of non-marine character. This unconformity is not found north of Santa Clara River, and some geologists place the division at the base of the conglomeratic sediments although marine fossils are present about 2,500 feet stratigraphically above this lithologic change. Surface structure projected across Santa Clara River indicates that the uppermost marine evidence found north of the river occurs at a stratigraphic position comparable with the marine strata directly under the local unconformity south of Santa Clara River. The coarse-grained marine sediments north of Santa Clara River have been included therefore in the Pico formation, and the Saugus formation, as applied to the Del Valle area, is limited to the overlying coarse-grained sediments of non-marine character.

STRUCTURE

General statement.—The Del Valle area is in a faulted and folded east-west synclinal basin at the eastern end of the Ventura basin of

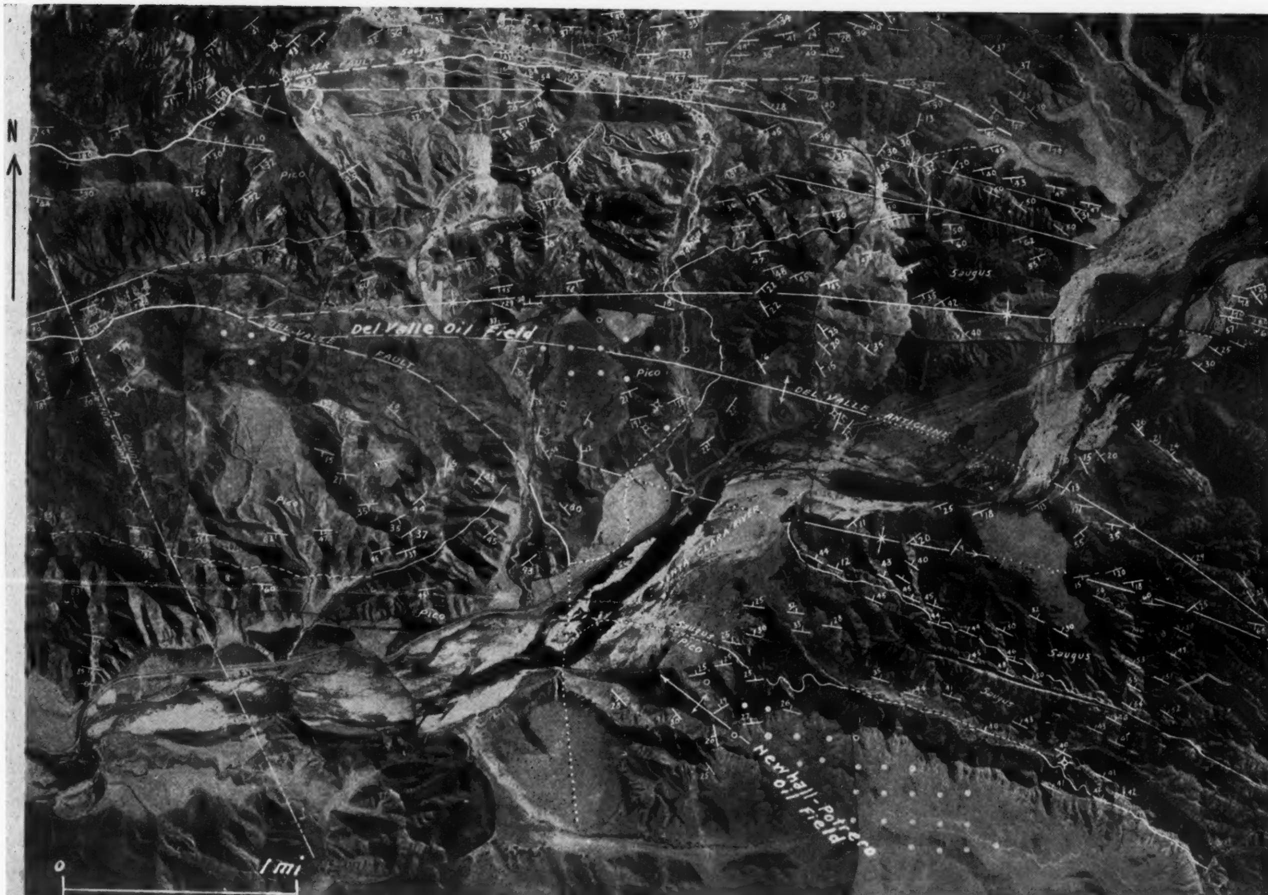

Fig. 2.—Geology of the Del Valle field and vicinity.

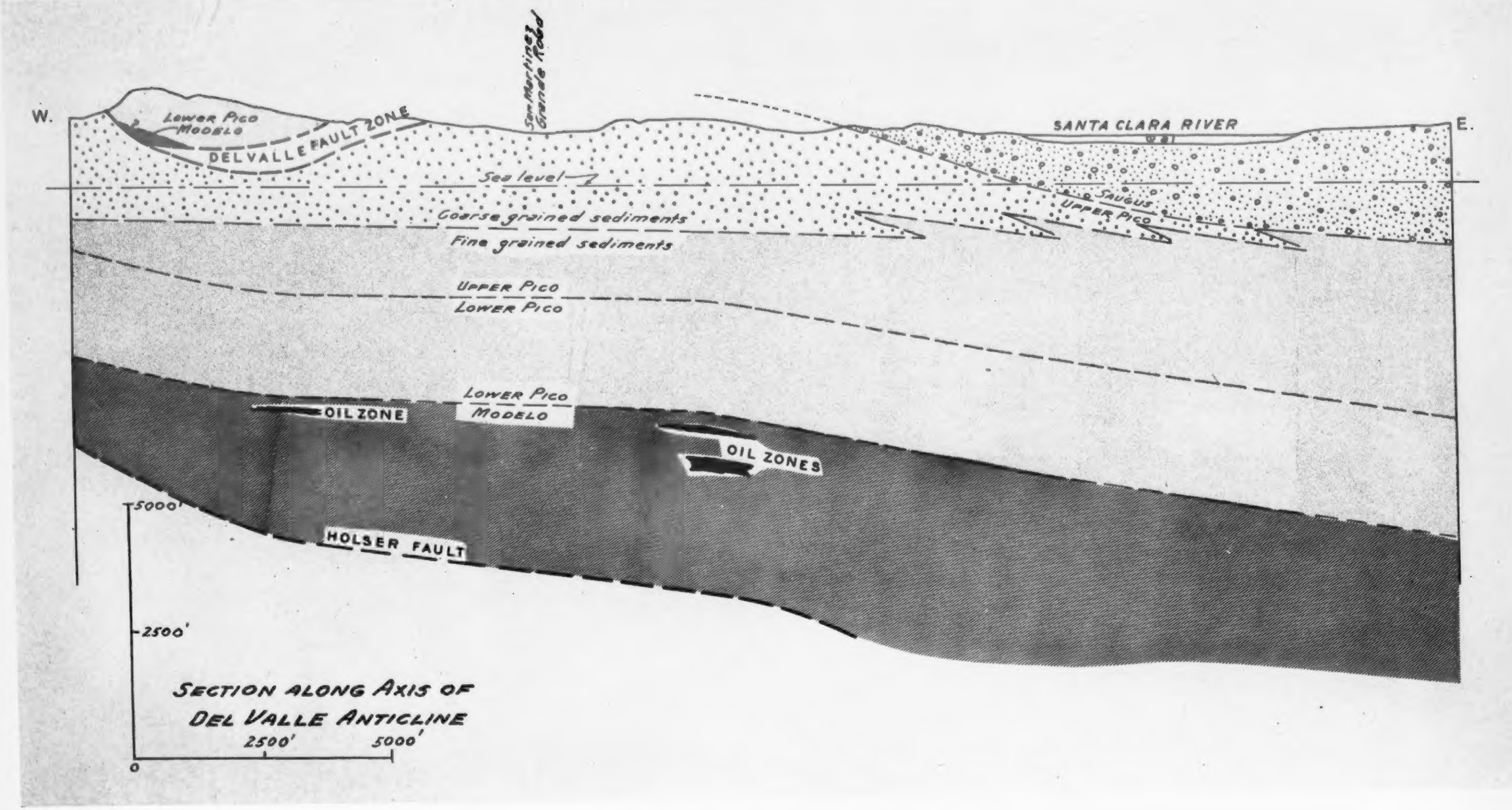

FIG. 3.—Section along axis of Del Valle anticline.

deposition. The Del Valle field is on one of these folds. Miocene sediments crop out within a few miles both north and south, and Pliocene sediments crop out along both sides of Santa Clara River between Piru and Castaic Junction.

Surface geology indicates that the productive limits of the Del Valle field are controlled on the north by the Holser fault, on the east by the easterly plunge of the folded sediments, and on the south by the south flank of the Del Valle anticline. The surface geologic interpretation of the western part of the field is obscured by the Del Valle fault (Fig. 2).

The Del Valle anticline plunges east and southeast about 18,000 feet from the discovery well, R. E. Havenstrite's Lincoln well No. 1. The structural relief or difference of structural elevation between the anticline and syncline on the north flank of the anticline just west of San Martinez Chiquito Canyon is about 250 feet. The structural relief on the north side of the anticline at the western area of production is obscured by the Del Valle fault; but, as the anticline has progressively less northern structural relief on the west, the structural relief north of the western area of production is probably less than 200 feet. Electric-log and well-core data indicate the western area of production to be at least 300 feet structurally higher than the eastern area. These facts indicate that the north flank of the Del Valle anticline can not form a structual trap on the north side of the field unless there is more structural relief at depth than there is at the surface.

The displacement on the Holser fault in San Martinez-Chiquito Canyon is not known. There may be as much as 4,000 feet of duplicated beds, but there is probably less than 2,000 feet. The surface trace strikes approximately east and west and the fault plane dips 50°–60° S. If the Holser fault has the same trend at depth that it does near the surface, it should truncate the upper producing zone two or three locations north of the discovery wells in both the east and west areas of production.

The Del Valle fault is a high-angle reverse, or thrust, fault with about 4,500 feet of duplicated sediments. It can be traced east from the town of Piru to the western area of production in the Del Valle field, southeast nearly parallel with San Martinez Grande Canyon, and south across Santa Clara River as a tear fault. The block on the south side of this fault overrides and obscures the structure of the west end of the Del Valle field.

There are several features capable of causing the trap on the west side of the Del Valle field. The producing zones may lens out toward the west to form a stratigraphic trap, north-south-trending cross

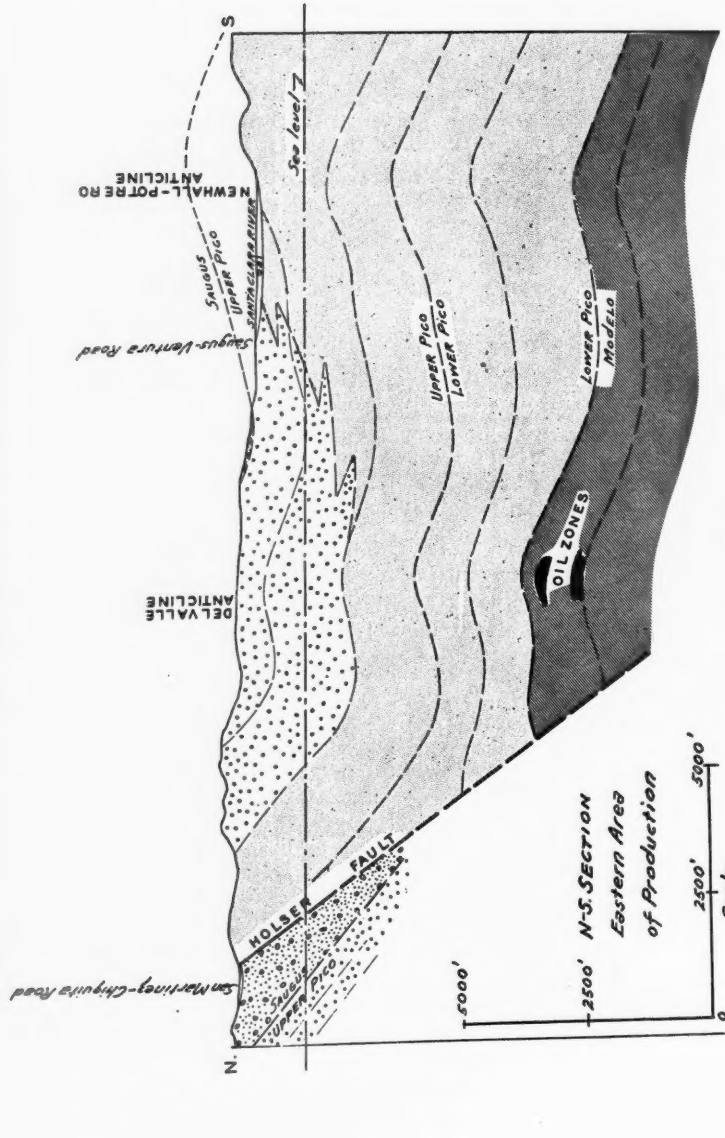

FIG. 4.—North-south section in eastern area of production.

faults may offset the producing zones sufficiently to form a fault trap, or there may be a reversal of plunge on the Del Valle anticline, with the western end of the anticline plunging westward under the Del Valle fault to form a structural trap. A combination of the first two of these features it the most probable, but subsurface data from wells drilled in the future will be needed to determine the true nature of the trap.

Del Valle oil field.—The discovery well of the Del Valle oil field was R. E. Havenstrite's Lincoln well No. 1. Eight additional wells, producing from a zone higher in the Miocene than the discovery well, have been completed in the same area. Two wells down structure, southeast of the discovery well that failed to produce oil, establish the southeastern productive limit of the present zones. The Jasper Petroleum Company's Videgain well No. 1, about 8,000 feet west of R. E. Havenstrite's Lincoln well No. 1, is producing from a zone comparable with the upper zone of production in the eastern area. Future development will probably join the two areas of production to form one oil field, although there will be complications due to minor faulting and sedimentary irregularities.

Subsurface structure.—Lithologic and paleontologic data from well cores and ditch samples, combined with electric-log records, are used to interpret the subsurface structure. Correlation of subsurface data in the eastern area of production verifies the development to be on an easterly plunging anticline. While there are insufficient subsurface data in the western area of production to establish the subsurface structure, the present tentative structural interpretation is shown diagrammatically in Figures 3, 4, and 5.

Zones of production.—There are two oil-producing zones now in the Del Valle oil field. The upper zone in the eastern area varies from 100 to 150 feet thick with water complications in the bottom part. The top of this zone is about 280 feet below the top of the Miocene. The initial production varies from 600 to 1,500 barrels per day of 32°–36° gravity oil with 250,000 to 1 million cubic feet of gas. The lower zone is about 200 feet thick and 900 feet below the top of the Miocene. The initial production was estimated at 300 barrels per day of 50° gravity oil, with 10 million cubic feet of gas. The gas zone was partly cased off, and the subsequent initial production was about 900 barrels per day of 33° gravity oil and 250,000 cubic feet of gas.

The one zone in the western area, now producing, is probably comparable with the upper zone of the eastern area. It is 100–150 feet thick and varies from 220 to 330 feet below the top of the Miocene. This variation may be due to faulting, the lenticular nature of the sediments, or an unconformity. The initial production varies from 400

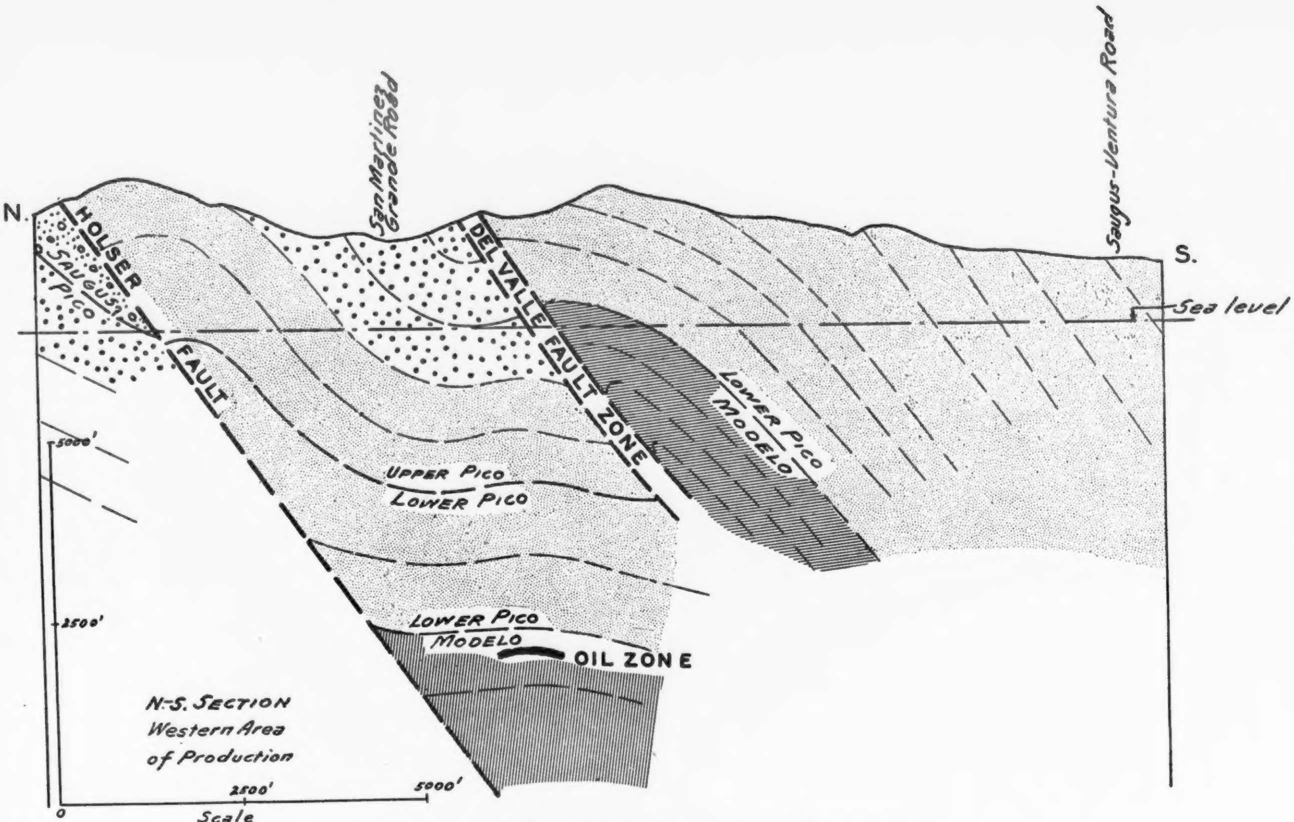

FIG. 5.—North-south section in western area of production.

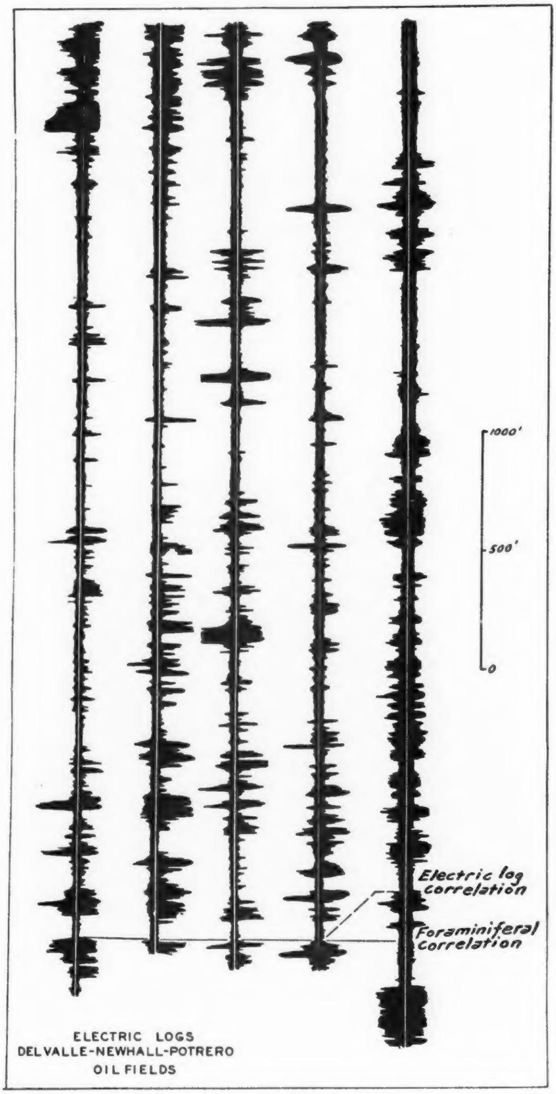

FIG. 6.—Typical electric logs in the Del Valle and Newhall-Potrero oil fields.

to 1,500 barrels per day of 31°–39° gravity oil with 1,500,000–6,500,000 cubic feet of gas. This zone also has water complications.

Electric-log data indicate that oil may be present in the lenticular sandstone of the lower Pico and upper Modelo as much as 700 feet above the top of the zone now producing in the western area of production.

Correlation of Del Valle and Newhall-Potrero oil fields.—Electric-log data indicate that the upper and lower zones of production in the Del Valle field are comparable with the first and third zones in the Newhall-Potrero field. More recent foraminiferal data indicate that the upper zone in the Del Valle field is probably correlative with the second zone in the Newhall-Potrero field. The Del Valle field is 800–1,000 feet structurally higher than the Newhall-Potrero field if the foraminiferal correlation is used (Fig. 6).

Detailed correlation by the use of electric-log data is very difficult due to the lenticular nature of the sediments. General correlation of the major sandstone and shale intervals can be made, but correlation of an individual stratum is almost impossible; therefore, the cause of irregularities of as much as 100 feet in the correlation of adjacent wells can not be determined. Such irregularities may be caused by faulting or by sedimentary changes. Experience with the wells drilled in the western area of production indicates that each well drilled in this part of the Del Valle field should be classed as a semi-wildcat venture.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 197-203, 1 FIG.

NEW INTERPRETATION OF SOME LACCOLITHIC MOUNTAINS AND ITS POSSIBLE BEARING ON STRUCTURAL TRAPS FOR OIL AND GAS[1]

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ABSTRACT

Each of the five Henry Mountains consists of a nearly symmetrical dome, several miles in diameter and a few thousand feet high. Their flanks are wrinkled by radial anticlinal noses, each a mile or two long and a few thousand feet wide. At the center of each dome is a stock, and evidence is presented to show that physical injection of the stocks produced the domes. The anticlinal noses were produced by elongate laccoliths injected radially from the stocks.

Igneous cores exposed at the centers of large domes at numerous localities in the United States and other countries have been interpreted generally as mushroom-shaped laccoliths and many of the domes have not been tested for oil and gas, perhaps because the arched strata are breached by erosion and the older strata were thought to pass undisturbed beneath the intrusion. Recent studies in the Henry Mountains, however, indicate that these domes may be produced by stocks as well as by laccoliths and it is suggested that oil or gas may be trapped on the flanks of such domes in oil-bearing regions in much the same way as oil and gas are trapped on the sides of salt domes.

INTRODUCTION

The mapping and reëxamination of the geology of the Henry Mountains by the writer were carried on from 1935 to 1939. The principal interest in the mountains is, of course, scientific because of Gilbert's classic report on them.[3] The laccoliths and other intrusive bodies in the Henry Mountains, at first thought, would appear to be of very little practical interest to geologists engaged in the search for oil or gas, but one of the conclusions reached in the recent study of the mountains may have some bearing as a guide in petroleum prospecting at localities in oil-producing regions that contain structural features related to intrusive bodies similar to those of the Henry Mountains.

The intrusive masses in the Henry Mountains include stocks, laccoliths, bysmaliths, dikes, and sills, but only the stocks and laccoliths are important in the present discussion. The laccoliths are elongate, tongue-shaped masses that were injected radially into the strata adjoining the stocks. The stocks are roughly cylindrical masses that cut discordantly across upturned strata. They have metamorphosed the adjacent strata much more intensely than have the laccoliths and have shattered the surrounding rocks for as much as a mile from their walls.

[1] Published with permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, July 14, 1941.

[2] United States Geological Survey.

[3] G. K. Gilbert, "Geology of the Henry Mountains," *U. S. Geol. and Geog. Survey of the Rocky Mountain Region* (Washington, 1877).

The structure of each of the five mountains considered in this paper is a nearly symmetrical dome several miles in diameter and a few thousand feet high. At the center of each dome is a stock of diorite porphyry. On top of each of the big domes are anticlinal noses a mile or two long and a few thousand feet wide that were produced by the laccoliths of diorite porphyry. The axes of these anticlinal noses, like the axes of the laccoliths, radiate from the stocks at the crests of the mountain domes (see map of Mount Hillers, Fig. 1).

The large, symmetrical mountain domes have resulted from the injection of the stocks and are not due to mushroom laccoliths as commonly assumed hitherto. If this conclusion is applicable to similar domes in areas containing petroliferous rocks, oil or gas may be trapped on the flanks of such domes in much the same way as oil and gas are trapped at the sides of salt domes.

ORIGIN OF THE MOUNTAIN DOMES

The stocks of each of the five mountain masses must have been emplaced by physical injection because the space occupied by the stocks would be closed if the formations turned up around the stocks were restored to their original horizontal position.

The structural domes of Mt. Pennell, Mt. Hillers, Mt. Holmes, and Mt. Ellsworth—the four southernmost masses of the Henry Mountains—and the dome at Navajo Mountain, 50 miles south, are each about 6 miles in diameter. The amount of uplift at the domes, however, is not the same, being about 2,600 feet at Navajo Mountain,[4] 3,500 feet at Mt. Holmes, 5,000 feet at Mt. Ellsworth, 6,000 feet at Mt. Pennell, and 7,000 feet at Mt. Hillers.

On Navajo Mountain no igneous rocks are exposed at the surface but, because of doming, the exposed strata that formerly spread over 28.25 square miles were stretched to cover an area of 28.75 square miles. In the Henry Mountains, however, the four southern domes represent greater uplift than at Navajo Mountain and stocks are exposed in each of them. The width of the stock in each of these four mountains is almost a direct function of the amount of uplift (Fig. 1).

In the portion of the Colorado Plateau of southeastern Utah, in which Navajo Mountain and the Henry Mountains are located, the doming of strata in a circular area 6 miles in diameter to a height of

[4] A. A. Baker, "Geology of the Monument Valley-Navajo Mountain Region, San Juan County, Utah," *U. S. Geol. Survey Bull. 865* (1936), Pl. 1.

at least 2,600 feet was accompanied by stretching and without the intrusion of stocks into the upper part of the dome. Navajo Mountain is an illustration of this type of deformation; its exposed strata were domed to a height of 2,600 feet and were stretched half a square mile. Greater uplift in areas of the same size in the Henry Mountains has resulted in the parting of the strata and the creation of space to accommodate the stocks. (See Fig. 1.) Mount Ellen, the fifth and northernmost of the Henry Mountains, is not considered in this discussion merely because the diameter of its dome is not the same as the diameter of the domes at the four southern Henry Mountains and at Navajo Mountain.

In each diagram the hypothetical area available for the intrusion of the stock has been reduced by an area equivalent to that representing the extent of the stretching of the strata. The field relations, illustrated by the maps and cross sections, are favorably comparable with the calculated space relations; moreover, almost perfect agreement can be attained if it is assumed that the limit to which the strata could be stretched by doming is a few hundred feet greater than at Navajo Mountain. It is concluded that the stocks in the Henry Mountains were emplaced by physical injection because the area of the tilted beds surrounding the stocks is equal to the area of those beds before deformation that accompanied intrusion of the stocks.

The cross sections of the cones representing the Henry Mountains illustrate the inadequacy of cross sections for measuring deformation. It will be noticed that on each cone the slant height of area *A* is less than the radius of the basal circle of the cone; in other words, if the lines representing this part of the lateral surface were restored to a horizontal position they would not meet. Such failure to meet, however, does not mean that parts of the strata are missing, because the area *A* of the lateral surface is as great as the horizontal area bounded by the basal circle of the cone. In effect, the upturned beds have been compressed radially and extended circumferentially, probably along shear planes. The extent to which such shearing occurred at the Henry Mountains can not be proved because the amount of deformation in the shatter zone surrounding the stocks can not be measured. Despite this difficulty, however, it is evident that the amount of deformation around an intrusive mass that has been physically injected must be measured areally and not along linear cross sections.

Although the evidence shows that the stocks in the Henry Moun-

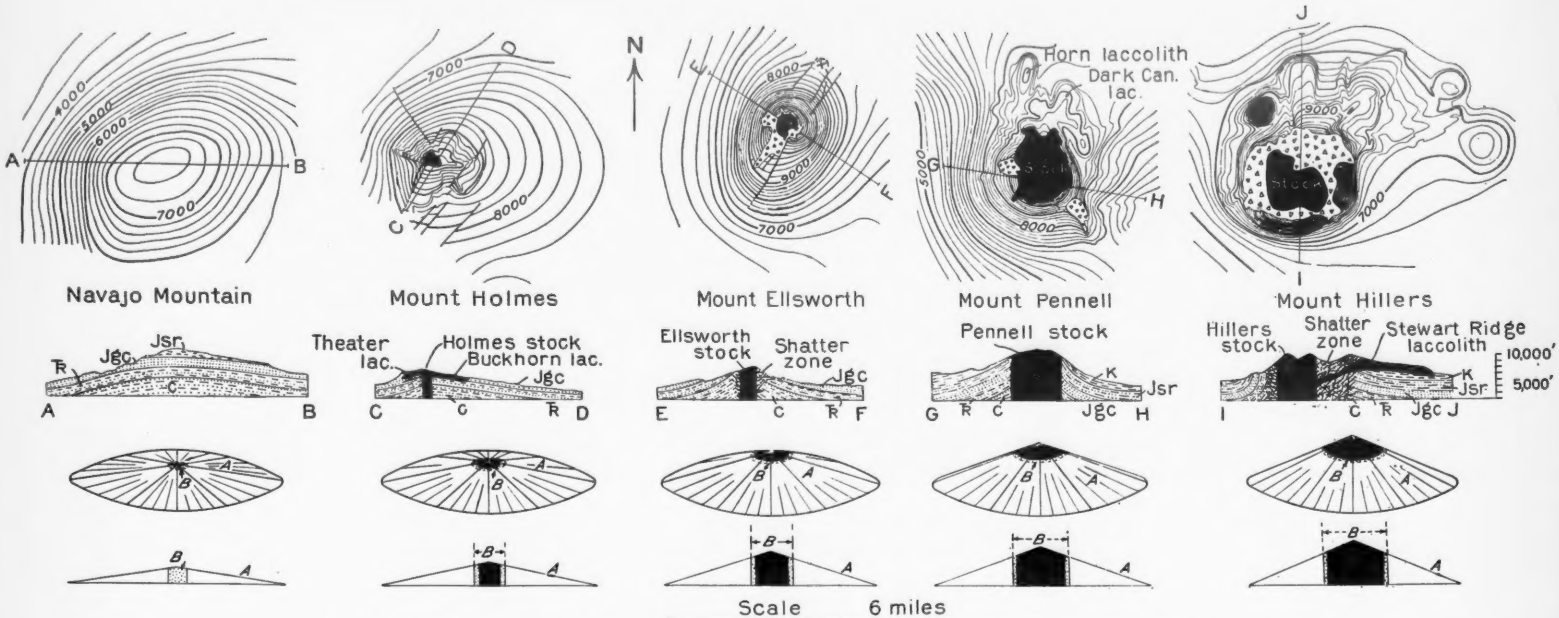

FIG. 1.—Structure contour maps, cross sections, and diagrams of Navajo Mountain and Mounts Holmes, Ellsworth, Pennell, and Hillers. The datum for the contours is mean sea-level. The contours are drawn on a formation above the exposed laccoliths. The location of the cross sections is shown by lines on the maps. The diagrams are on the same scale as the structure-contour maps and geologic cross sections of the mountains. Each diagram is set beneath the mountain it portrays. In the oblique diagrams of the conically deformed circular areas: (1) the lined area *A* on the lateral surface of each cone equals the area of the basal circle; and (2) the area *B* is the amount by which the lateral surface exceeds the circular base.

The stippled area *B* (0.5 sq. mi.) on the Navajo Mountain cone represents the extent of stretching of the domed strata. Areas of the same size are represented by stippling on the other cones. On the assumption that this 0.5 square mile is the limit of stretching of the strata, the black areas in the cones of the Henry Mountains represent the theoretical space formed by the doming of the strata and available for the intruding stock.

K, Cretaceous; Jsr, San Rafael group (Jurassic); Jgc, Glen Canyon group (Jurassic?); Tr, Triassic; C, Carboniferous.

tains were forcibly injected, the large domes around the stocks are not necessarily the result of that injection. Four hypotheses may be considered to explain the domes.

1. They may be due to horizontal orogenic stresses.
2. They may be due to the aggregate uplifting effect of the many relatively small laccoliths and sills.
3. They may be due to arching by one huge, deeply buried laccolith of mushroom form.
4. They may be due to a vertical push, as if by the stocks.

The first two hypotheses can be practically disproved. The fact that the domes are so nearly circular in a region of linear uplifts seems to eliminate horizontal compression as a cause. The fact that the flanks of the large domes are smooth and not wrinkled indicates that they are not due to the aggregate uplifting effect of many small domes. It is safe to conclude that the Mt. Ellsworth dome, for example, houses no laccoliths like those on the north side of Mounts Pennell and Hillers (Fig. 1).

The large domes may be due to arching over a deeply buried laccolith, but this interpretation requires the assumption of an almost perfectly symmetrical, mushroom laccolith, whereas the known laccoliths are tongue-shaped, elongate bulges from the central stocks; moreover, the volume of the assumed mushroom laccolith would have to be 20 times larger than the largest known laccolith in the Henry Mountains and about 50 times larger than the average volume of the known laccoliths in the Henry Mountains. Also, practically all of the known laccoliths were intruded into the Upper Jurassic and Upper Cretaceous formations. The absence of anticlinal noses in the older formations precludes the presence of similar laccoliths in those formations, so the assumed mushroom laccolith would have to be in a part of the stratigraphic section that was avoided by the known laccoliths. Finally, the only symmetrical laccoliths that are known are very small, like the Shonkin Sag in Montana. For a laccolith to produce one of the major domes at the Henry Mountains about 9 cubic miles of igneous rock, which is about 125 times the volume of the Shonkin Sag laccolith, would be required, and the growth of a mushroom laccolith to such huge size probably would result in imperfect form. This negative reasoning leads to the belief that the forcible injection of the stocks was responsible for the large mountain domes.

APPLICATION TO OTHER AREAS

The simplicity of the mushroom form of laccolith, as conceived by Gilbert, has provided an appealing explanation for large domal uplifts

in regions of little folding, like the Henry Mountains. A result of this conception is that discordant relations between the intrusive mass and the domed strata have been minimized and the observed apparent concordant relations have been stressed. Discordant relations between igneous intrusive masses and the adjacent strata are largely measured in a vertical plane, a direction in which the geologist ordinarily has little information; on the other hand, the land surface that truncates a dome containing a centrally located intrusive mass exposes the dome in the least favorable direction for revealing discordance.

In the Piatigorsk region, north of the Caucasus, for example, the domed strata are apparently concordant on the igneous cores of the numerous domes, yet the discordance found in the distance of a mile at the surface amounts to 1,500 feet.[5] The igneous core at South Moccasin Mountain, Montana, and at Carrizo Mountain, Arizona, likewise seem to be concordant, yet the discordance in a distance of a mile at the surface amounts to 1,000 feet.[6] The discordance across the surface of the igneous core at Marysville Buttes, California, amounts to 1,600–1,700 feet in a distance of three miles.[7] At Bear Butte, South Dakota, the discordance aggregates 1,500 feet in three-quarters of a mile at the surface.[8] The observed discordance at these domes is of course only a minimum, but the discordance has been assumed to be almost the maximum and each dome has been attributed to a buried laccolith of the mushroom type. Probably the extreme example of such explanation is illustrated by the dome at Nördlingen, Germany, which has been attributed to an entirely concealed mushroom laccolith that developed in granite.[9]

Many other examples could be cited. Usually it has been stated that the laccolithic intrusive form has been assumed merely as a convenient means of emphasizing the doming by igneous intrusion. These domes, however, are like the large mountain domes around the stocks in the Henry Mountains and are not at all like the anticlinal noses produced

[5] Vera de Derwies, *Recherches Geologiques et Petrographique sur les Laccolites des Environs de Piatigorsk* (Geneva, 1908).

[6] H. S. Palmer, "Structure of the South Moccasin Laccolith, Fergus County, Montana," *Amer. Jour. Sci.*, Vol. 10 (1925), p. 120, Fig. 3.
W. B. Emery, "The Igneous Geology of Carrizo Mountain," *Amer. Jour. Sci.*, Vol. 42 (1916), pp. 349–63.

[7] Howel Williams, "Geology of the Marysville Buttes, Calif.," *Calif. Univ. Dept. Geol. Sci. Pub.*, Vol. 18 (1929), p. 147.

[8] T. A. Jaggar, Jr., "The Laccoliths of the Black Hills," *U. S. Geol. Survey 21st Ann. Rept.* (1901), Pl. 30.

[9] W. Branco and E. Fraas, "Das Vulcanische Ries bei Nördlingen in seiner Bedeutung für der allgemeine Geologie," *Abh. k. preuss. Akad. Wiss. Berlin* (1901), pp. 1–169.

by the radiating laccoliths. Although it is perfectly true that the domes could be the result of arching over laccoliths they could as readily be the result of doming by stocks like those in the Henry Mountains. The object of this paper is to stress the need for reconsidering the explanations hitherto applied to large symmetrical domes associated with igneous intrusives.

Domes that have been produced by the intrusion of stocks may prove to be suitable structural traps for oil or gas in some areas. The oil or gas presumably would accumulate subsequent to the deformation and so the heat of intrusion is not necessarily a complicating factor. Drilling, however, might be expensive on account of associated sills and dikes. The drilling of half a dozen wells during the past few years at Marysville Buttes, California, tends to confirm the general conclusion reached at the Henry Mountains. One of these wells, located within a few hundred feet of the exposed edge of the central intrusive mass, was drilled to a depth of 7,014 feet and in that depth encountered only sills in the domed strata, thereby effectively demonstrating that the central intrusive mass is not a mushroom laccolith. The failure of test wells on the uplifts in southeastern Utah gives no encouragement to the testing of the large domes at the Henry Mountains but similar structures may prove productive in oil-bearing regions.

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SUBSURFACE GEOLOGY OF SEWELL-EDDLEMAN AREA, YOUNG COUNTY, TEXAS[1]

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ABSTRACT

The Sewell-Eddleman area in Young County, Texas, was discovered in January, 1937. Fifty-nine oil or gas wells have been completed to date and six producing zones have been encountered at depths ranging from 2,300 to 4,500 feet, all in rocks of lower Pennsylvanian age except the lowest zone which is Mississippian in age. The limits of the producing area are not yet defined.

The structure of the area is described as an east-west trending anticline, approximately 6 miles long and 2 miles wide, cutting across the axis of the Bend arch. Evidence now available indicates that folding increases with depth. Subsurface structure maps on two horizons, four cross sections through wells, and supporting, tabulated well data present the principal structural and stratigraphic facts about the area.

LOCATION

The Sewell-Eddleman area is in southeastern Young County, Texas, 2–8 miles east and a little south of Graham, the county seat.

The east part of the area, east of the Brazos River Indian Reserve, is designated by the Railroad Commission of Texas as the Sewell field; the part west of the east line of the Indian Reserve and not included in the Sewell field is called the Eddleman area.

ACKNOWLEDGMENTS

The writers of this article wish to acknowledge the courtesy of the Union Producing Company, A. R. Eppenauer, Henry Zweifel, the Cosden Petroleum Corporation and John W. Herbert (the Falcon Company) for giving permission to publish the electrical logs of several of their wells. Appreciation is also expressed to Thomas Nichols for his work in drafting the maps and cross sections and to Mrs. Jeanne White for typing.

INTRODUCTION

The subsurface folding included within the Sewell-Eddleman area, both in areal extent and amount of uplift, is one of the outstanding structural features of that well known geologic province located in the Pennsylvanian area of north-central Texas, commonly called the Bend arch or Bend flexure. Because of its interesting subsurface structure, the information secured in regard to oil possibilities of the deep formations, and also because it is located in one of the most widely pros-

[1] Manuscript received, July 3, 1941; revised, November 21, 1941.

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pected and earliest "boom" sections of Texas, the area is deemed to be of sufficient interest to justify recording the principal geological facts observed during the course of development.

Fifty-nine producing oil or gas wells have been completed within the area, and six producing zones have been encountered at depths ranging from 2,300 to 4,500 feet. The principal producing zone thus far developed is the so-called Sewell "pay," a porous zone in the lower part of the Caddo limestone of Pennsylvanian age. Another porous zone found near the top of the Caddo has yielded gas in varying quantities throughout the area. Other producing zones of Pennsylvanian age are the "Rhodes" sand of the Strawn group, the "Eddleman" sand found just above the Marble Falls limestone in this area, and a zone of porosity in the top of the Marble Falls limestone itself. The Chappel limestone of Mississippian age has yielded one well in the area.

Two tests have penetrated the Ellenburger limestone (Ordovician), one for more than 300 feet.

The structure and producing area of the Sewell field have been rather closely defined by wells on the north flank of the fold, but in the Eddleman area and on the south and east sides of the Sewell field, fewer wells have been drilled and the structure and extent of the productive area are less definite.

At present, it is estimated that the area proved for oil production amounts to about 1,800 acres, and the proved gas-producing area covers 1,500 acres.

More than ½ million barrels of oil have been produced from the Sewell-Eddleman area, most of it since June, 1938, when the first oil well was completed in the Sewell "pay." The total gas production to date amounts to about 4 billion cubic feet.

All oil wells in the Sewell "pay," with one exception, and all oil wells completed in the Marble Falls limestone are flowing wells.

Initial shut-in pressures of wells in the Sewell "pay" average 1,485 pounds, and for wells in the Marble Falls limestone 1,750 pounds.

The oil found in the Sewell-Eddleman area is "sweet oil" with a gravity of 43° A.P.I.

During the past 20 years or more, the surface geology of the Sewell-Eddleman area has been mapped by many capable geologists, but because of lack of satisfactory surface control, the results of this type of work did not encourage extensive deep development.

Subsurface data available from wells drilled before 1936–1937 indicated the presence of a large fold, and it was on the basis of this information (determined independently of each other), that the writers

recommended the area to their respective clients for the acquisition of acreage and the drilling of deep test wells.

HISTORY

The first test drilled in the Sewell-Eddleman area was the Producers Oil Company's (The Texas Company) Eddleman No. 1 (map No. 37), completed as a dry hole in the Strawn at 2,689 feet in the year 1912. The Monroe Production Company's Bridwell No. 1 (map No. 24), abandoned early in 1923 in the Marble Falls limestone at the total depth of 4,425 feet, was the second test drilled. These wells are at the extreme west and east edges, respectively, of the Sewell-Eddleman area. Subsequently, between 1923 and 1937, eleven tests were drilled on, or adjacent to, the structure. Only one of these tests, Crenshaw's Turner No. 1 (map No. 11), penetrated the Caddo limestone, but it was non-productive. The other ten tests stopped in the Strawn, and of these, only two were completed as producing wells, the Panhandle Oil and Refining Company's Cox No. 1 and Steele No. 1 (maps Nos. 29 and 30). These wells, completed in 1930, were both small oil wells in the "Rhodes" sand of the Strawn, and were the first commercial producers in the Sewell-Eddleman area.

In February, 1937, A. R. Eppenauer completed his Eddleman No. 1 (map No. 12) in the "Eddleman" sand as a gas well with an initial production of about 40 million cubic feet per day. Active development then began, and on August 15, 1937, Henry Zweifel's Sewell No. 1-A (map No. 60) was brought in, also having an initial gauge of nearly 40 million cubic feet of gas produced from the Marble Falls limestone and the Chappel limestone.

Fifty-seven producing wells (forty-five oil wells and twelve gas or gas-distillate wells) have been completed and six dry holes have been drilled in the area up to the time this report goes to press.

STRATIGRAPHY

It is considered unnecessary to include here a detailed description of beds encountered in wells drilled through the Pennsylvanian and older sections, as the characteristics of these formations have been adequately described in other reports. In this article, the stratigraphic classification of Paleozoic strata of north-central Texas published by Sellards[4] has been used, since his work summarizes the classifications used in earlier publications. The present writers have endeavored to reconcile a few of the earlier formation names and boundaries long ap-

[4] E. H. Sellards, "The Geology of Texas," Vol. I, *Univ. Texas Bull. 3232* (1932), pp. 98–115.

plied to the Pennsylvanian beds with names and subdivisions recently proposed or coming to be recognized by geologists, but it is not within the scope of this article to attempt the solution of any complicated, regional, stratigraphic problems.

Of the 5,000 feet of sediments penetrated in the Sewell-Eddleman area, approximately 4,500 feet belong to the Pennsylvanian system, 200 feet to the Mississippian, and 300 feet to the Ordovician. The cross sections in Figures 1, 4, 5, and 6, compiled from drillers' logs, sample determinations, and electrical logs, illustrate the lithologic characteristics of the beds and principal stratigraphic subdivisions of the area. In the following paragraphs is given a brief summary of these formations, arranged in descending order as encountered in wells in the Sewell-Eddleman area.

PENNSYLVANIAN SYSTEM

Cisco group.—The Sewell-Eddleman area lies within the outcrop of beds belonging to the Graham formation of the Cisco group. The Bunger limestone member of this formation is found at or near the surface in most of the area, mantled, however, by a coarse conglomerate of the Cisco group which obscures the Bunger outcrop and renders surface mapping difficult.

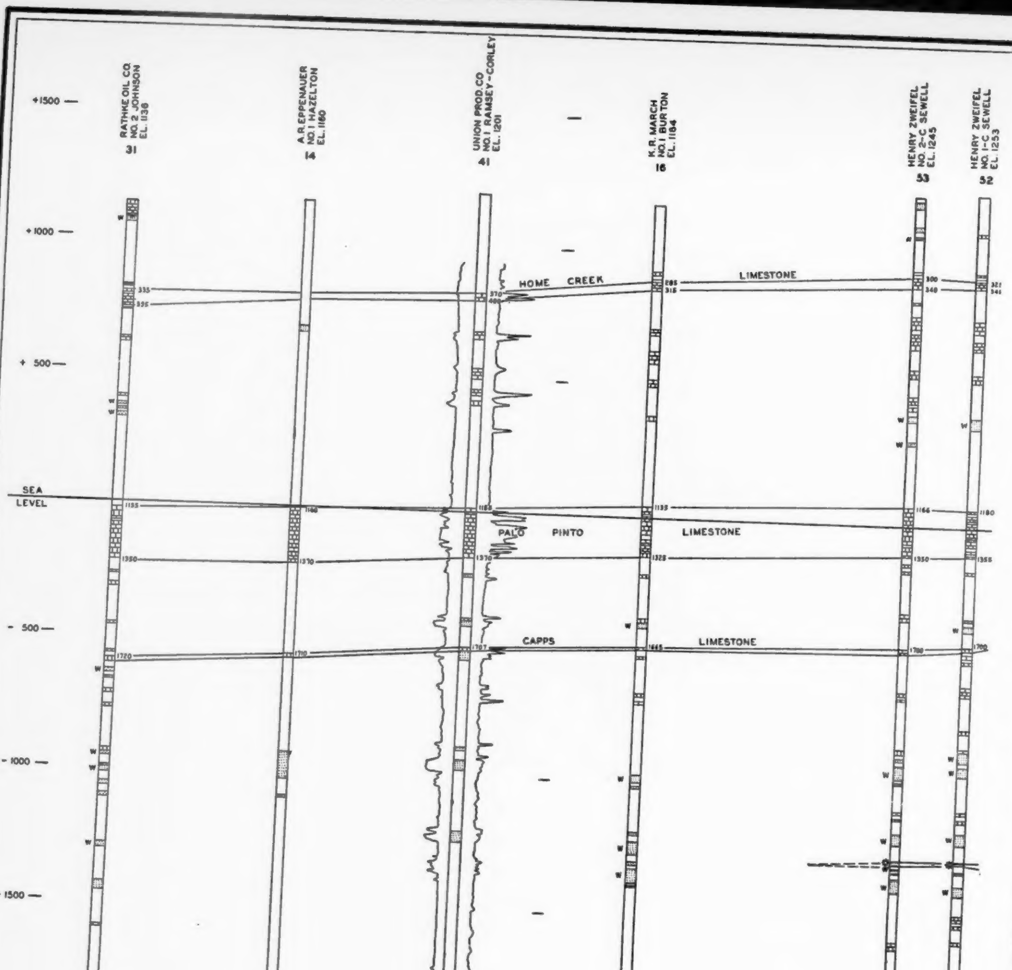
Wells begin in the Graham formation of the Cisco group and pass through approximately 250–300 feet of predominantly gray shale with thin limestone and sandstone members comprising this group. A thin red shale bed, just above the top of the Home Creek limestone, interpreted by some as a zone of weathering,[5] commonly occurs in this area.

Canyon group.—Beds of the Canyon group consist of thick limestones, alternating with shales and some sandstones, and have a total thickness of approximately 1,050 feet. Authorities appear to agree that the top of the Home Creek limestone marks the top of the Canyon group, whereas there is less agreement in regard to the base. Sellards[6] delimits the Canyon group at the base of the Palo Pinto limestone. Cheney,[7] however, places the lower boundary of his "Canyon series" at the "unconformity or disconformity which separates the Lake Pinto sandstone from the East Mountain shale at Mineral Wells." On the cross sections shown in Figures 1, 4, 5, and 6, this unconformity should occur in the interval between the base of the Palo Pinto lime-

[5] M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), p. 90.

[6] E. H. Sellards, *op. cit.*, pp. 105 and 110.

[7] M. G. Cheney, *op. cit.*, pp. 87 and 89.



RATHKE OIL CO. NO. 2 JOHNSON EL. 1136
31
A.R. EPPENAUER NO. 1 HAZELTON EL. 1160
14
UNION PROD. CO. NO. 1 RAMSEY-CORLEY EL. 1201
41
K.R. MARCH NO. 1 BURTON EL. 1184
16
HENRY ZWEIFEL NO. 2-C SEWELL EL. 1245
53
HENRY ZWEIFEL NO. 1-C SEWELL EL. 1253
52
+1500
+1000
+500
SEA LEVEL
-500
-1000
-1500
-2000
-2500
-3000
-3500
HOME CREEK LIMESTONE
PALO PINTO LIMESTONE
CAPPS LIMESTONE
BLACK SHALE
TOP OF GRAY LIME
SMITHWICK FORM'N
CADDO LIME
BLACK SHALE WITH SAND & LIME
MARBLE FALLS FORM'N.

FIG. 1A

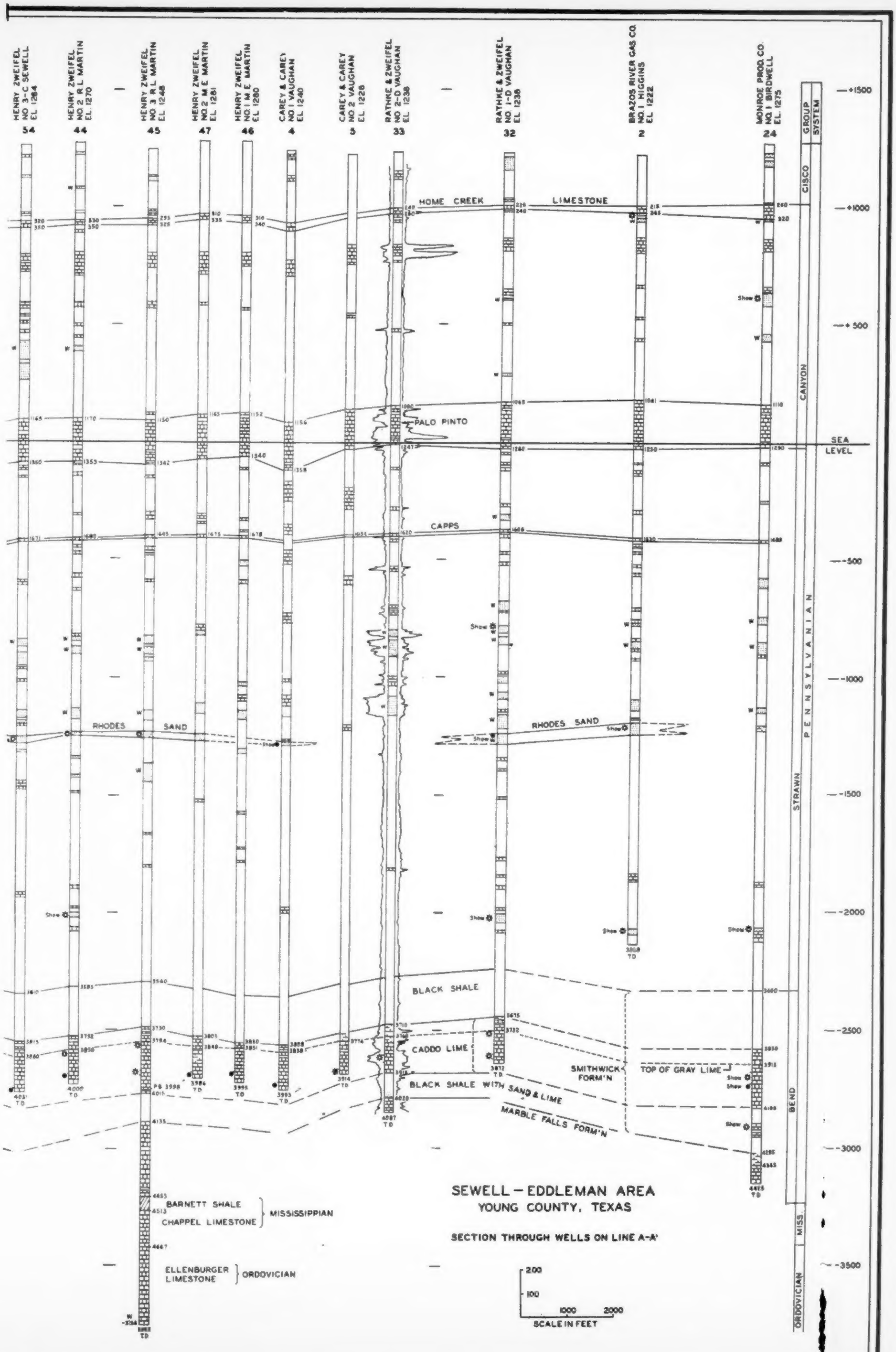

HENRY ZWEIFEL NO 3-C SEWELL EL 1264
HENRY ZWEIFEL NO 2 R L MARTIN EL 1270
HENRY ZWEIFEL NO 3 R L MARTIN EL 1248
HENRY ZWEIFEL NO 2 M E MARTIN EL 1281
HENRY ZWEIFEL NO 1 M E MARTIN EL 1260
CAREY & CAREY NO 1 VAUGHAN EL 1240
CAREY & CAREY NO 2 VAUGHAN EL 1228
RATHKE & ZWEIFEL NO 2-D VAUGHAN EL 1238
RATHKE & ZWEIFEL NO 1-D VAUGHAN EL 1238
BRAZOS RIVER GAS CO. NO 1 HIGGINS EL 1222
MONROE PROD. CO. NO 1 BIRDWELL EL 1275
HOME CREEK LIMESTONE
PALO PINTO
SEA LEVEL
CAPPS
RHODES SAND
BLACK SHALE
CADDO LIME
SMITHWICK FORM'N
TOP OF GRAY LIME
BLACK SHALE WITH SAND & LIME
MARBLE FALLS FORM'N
BARNETT SHALE
CHAPPEL LIMESTONE
MISSISSIPPIAN
ELLENBURGER LIMESTONE
ORDOVICIAN
GROUP
SYSTEM
CISCO
CANYON
STRAWN
BEND
MISS
PENNSYLVANIAN
SEWELL – EDDLEMAN AREA
YOUNG COUNTY, TEXAS
SECTION THROUGH WELLS ON LINE A-A'
SCALE IN FEET

FIG. 1B

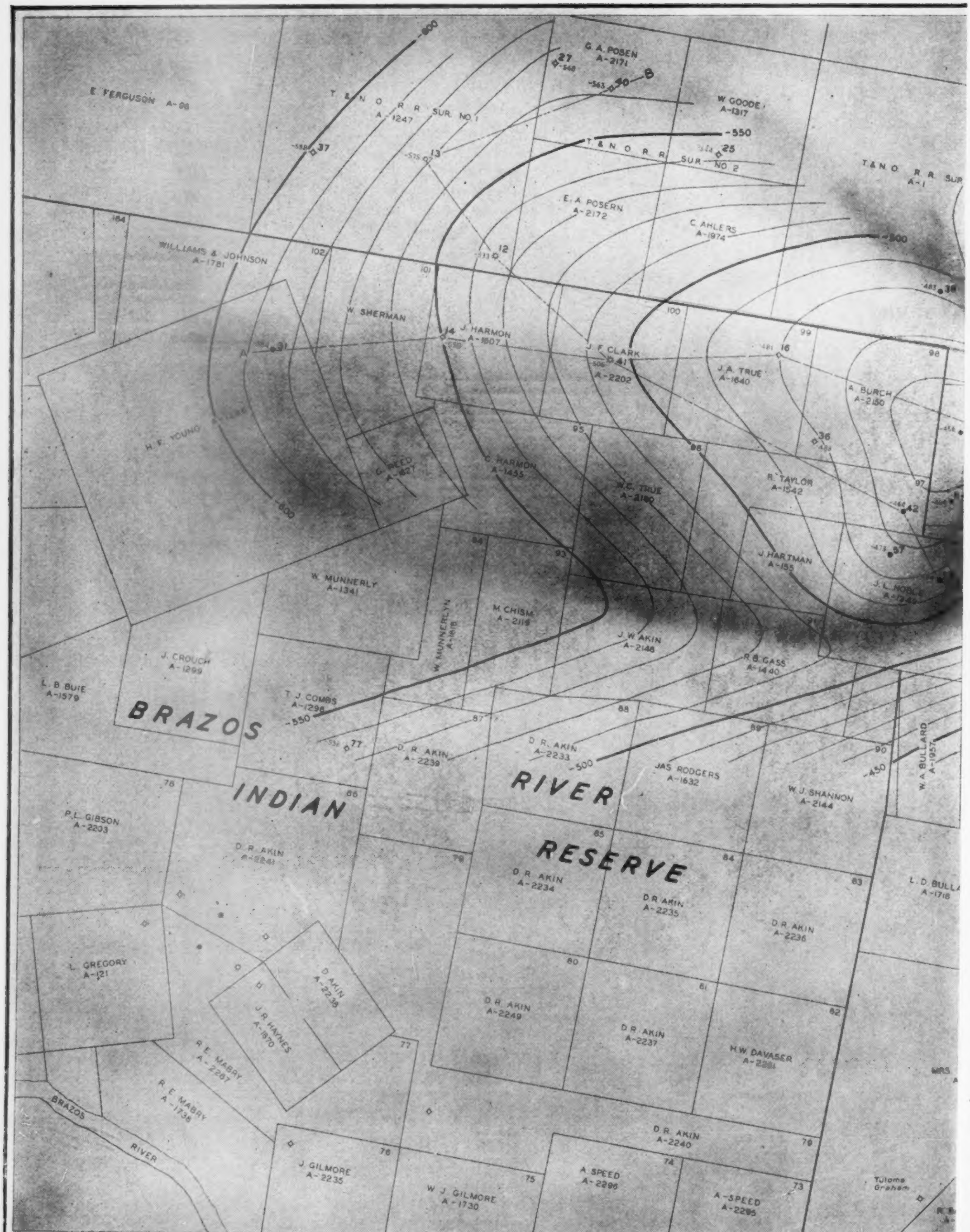
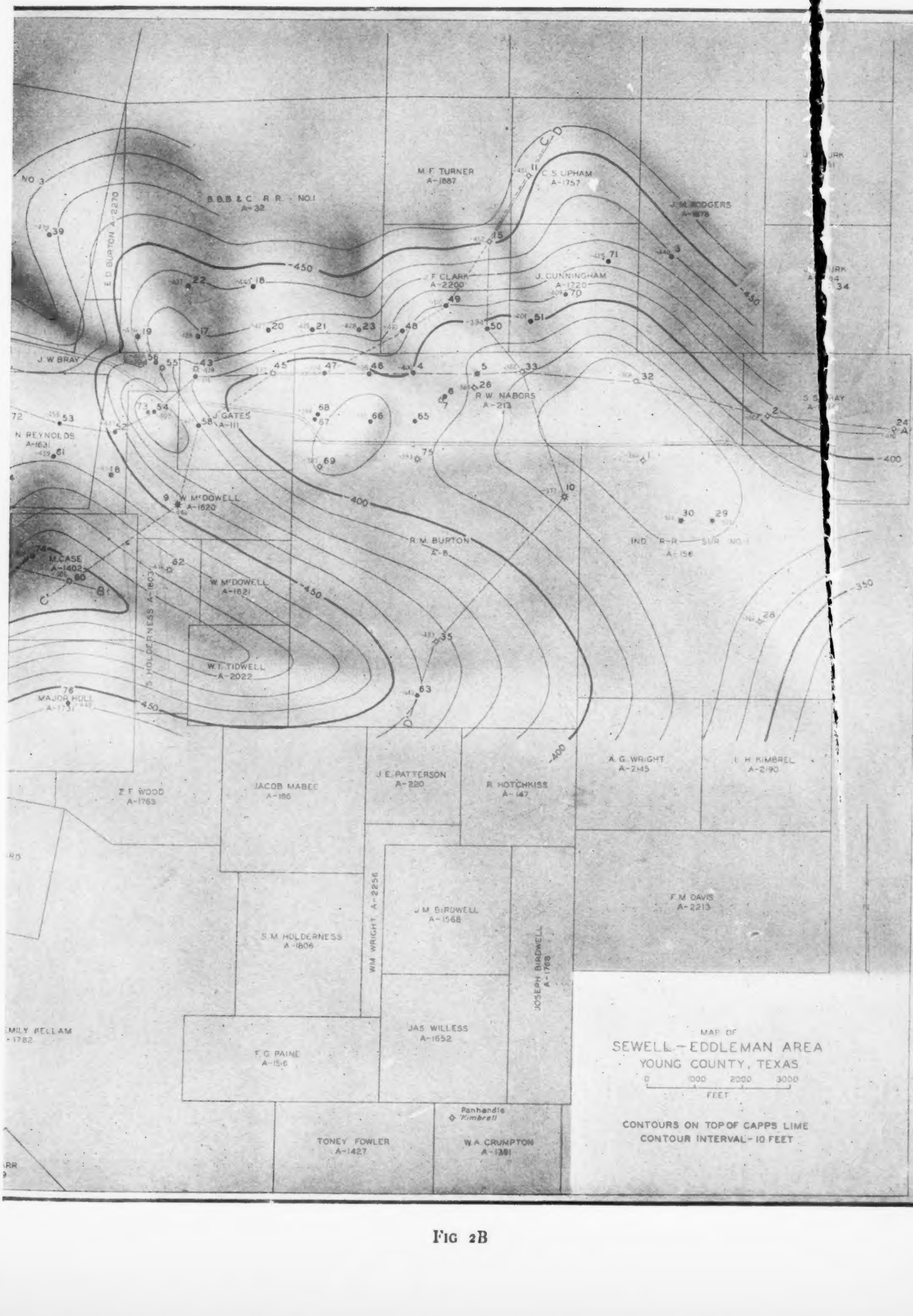

E FERGUSON A-98
T & N O R R SUR. NO 1
A-1247
G A POSEN
A-2171
B
W GOODE
A-1317
-550
T & N O R R SUR NO 2
T & N O R R SUR
A-1
E. A. POSERN
A-2172
C. AHLERS
A-1974
-500
WILLIAMS & JOHNSON
A-1781
W SHERMAN
J. HARMON
A-1807
J. F CLARK
A-2202
J. A. TRUE
A-1640
A. BURCH
A-2150
H. F. YOUNG
C. REED
A-1827
C. HARMON
A-1455
W. C. TRUE
A-2180
R. TAYLOR
A-1542
J. HARTMAN
A-155
J. L. NOBLE
W. MUNNERLY
A-1341
W. MUNNERLYN
A-1818
M. CHISM
A-2119
J. W. AKIN
A-2146
R. B. GASS
A-1440
J. CROUCH
A-1299
L. B BUIE
A-1579
T. J. COMBS
A-1296
BRAZOS
INDIAN
RIVER
RESERVE
D. R. AKIN
A-2239
D. R. AKIN
A-2233
JAS RODGERS
A-1632
W. J. SHANNON
A-2144
W. A. BULLARD
A-1257
P. L. GIBSON
A-2203
D. R. AKIN
A-2241
D. R. AKIN
A-2234
D. R. AKIN
A-2235
D. R. AKIN
A-2236
L. D. BULLA
A-1718
L. GREGORY
A-121
D. AKIN
A-2238
J. R. HAYNES
A-1870
D. R. AKIN
A-2249
D. R. AKIN
A-2237
H. W. DAVASER
A-2281
R. E. MABRY
A-2287
R. E. MABRY
A-1738
BRAZOS
RIVER
D. R. AKIN
A-2240
J. GILMORE
A-2235
W. J. GILMORE
A-1730
A. SPEED
A-2296
A. SPEED
A-2295
Tulome
Graham

FIG. 2A



MAP OF
SEWELL - EDDLEMAN AREA
YOUNG COUNTY, TEXAS
0 1000 2000 3000
FEET
CONTOURS ON TOP OF CAPPS LIME
CONTOUR INTERVAL - 10 FEET
M.F. TURNER A-1887
C.S. UPHAM A-1757
J.M. RODGERS A-1878
B.B.B. & C. R.R. NO. 1 A-32
E.D. BURTON A-2270
J.F. CLARK A-2200
J. CUNNINGHAM A-1720
J.W. BRAY
R.W. NABORS A-213
J. GATES A-111
N. REYNOLDS A-1631
W. McDOWELL A-1620
R.M. BURTON A-8
IND. R-R SUR. NO. 1 A-156
M. CASE A-1402
W. McDOWELL A-1621
S. HOLDERNESS A-1803
W.T. TIDWELL A-2022
MAJOR HULL A-1731
Z.F. WOOD A-1763
JACOB MABEE A-186
J.E. PATTERSON A-220
R. HOTCHKISS A-147
A.G. WRIGHT A-2145
I.H. KIMBREL A-2190
F.M. DAVIS A-2213
J.M. BIRDWELL A-1568
WM WRIGHT A-2256
S.M. HOLDERNESS A-1806
JOSEPH BIRDWELL A-1768
JAS. WILLESS A-1652
F.G. PAINE A-1516
EMILY KELLAM A-1782
TONEY FOWLER A-1427
Panhandle Kimbrell
W.A. CRUMPTON A-1381
S.S. GRAY
-450
-400
-350

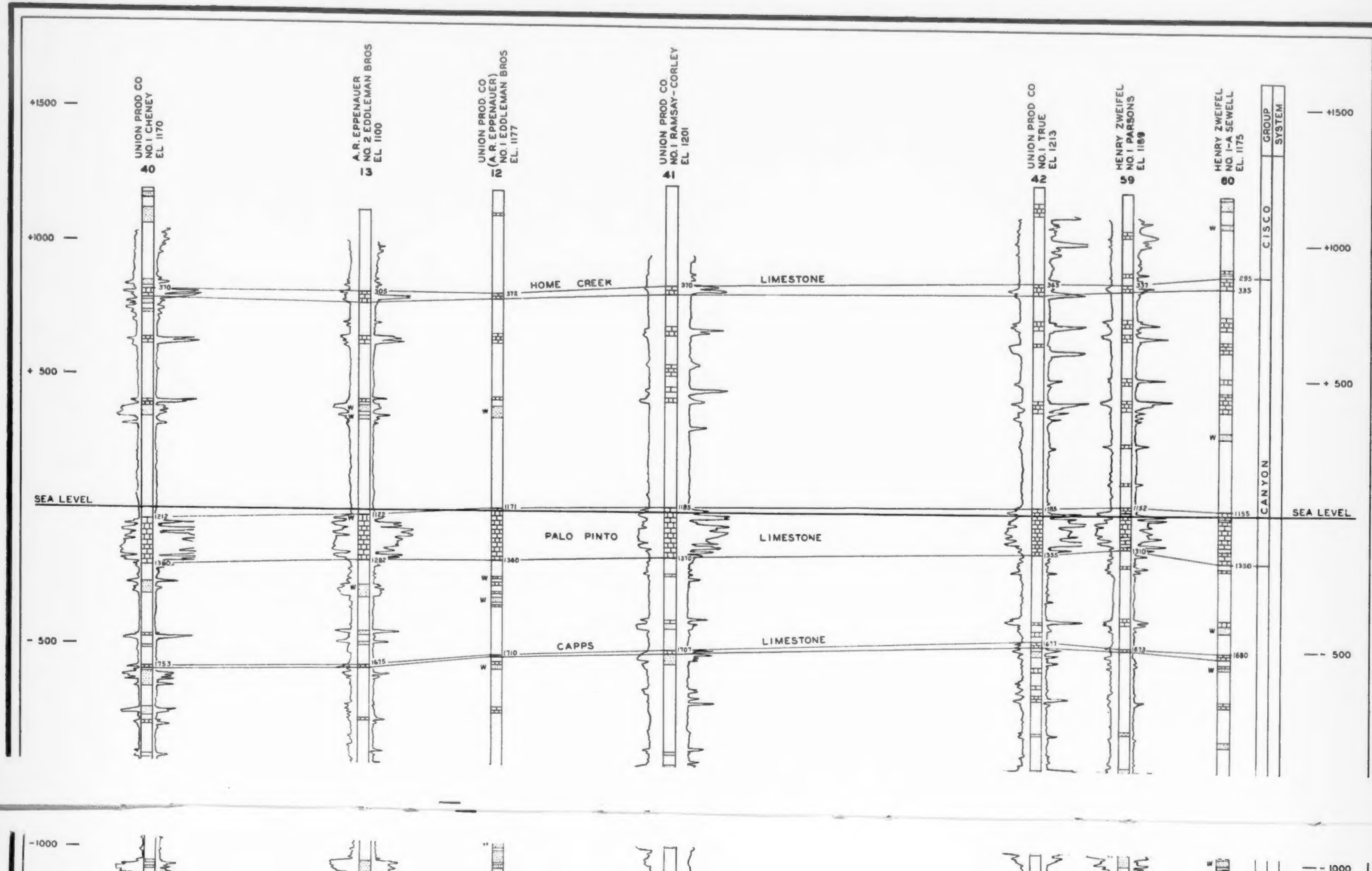
FIG 2B


E. FERGUSON A-96
G. A. POSEN A-2171
W. GOODE A-1317
T & N. O. R. R. SUR. NO. 1 A-1247
T & N. O. R. R. SUR. NO. 2
T & N. O. R. R. SUR. A-1
E. A. POSERN A-2172
C. AHLERS A-1974
WILLIAMS & JOHNSON A-1781
W. SHERMAN
J. HARMON A-1607
J. F. CLARK A-2202
J. A. TRUE A-1640
A. BURCH A-2150
H. F. YOUNG A-1286
G. REED A-1627
C. HARMON A-1455
W. C. TRUE A-2180
R. TAYLOR A-1542
J. HARTMAN A-155
W. MUNNERLY A-1341
W. MUNNERLYN A-1816
M. CHISM A-2119
J. W. AKIN A-2148
R. B. GASS A-1440
J. CROUCH A-1299
L. B. BUIE A-1579
T. J. COMBS A-1298
D. R. AKIN A-2239
D. R. AKIN A-2233
JAS. RODGERS A-1832
W. J. SHANNON A-2144
W. A. BULLARD A-1957
BRAZOS INDIAN RIVER RESERVE
P. L. GIBSON A-2203
D. R. AKIN A-2241
D. R. AKIN A-2234
D. R. AKIN A-2235
D. R. AKIN A-2236
L. D. BULLA A-1718
L. GREGORY A-121
D. AKIN A-2238
J. R. HAYNES A-1870
D. R. AKIN A-2249
D. R. AKIN A-2237
H. W. DAVASER A-2261
R. E. MABRY A-2287
R. E. MABRY A-1738
BRAZOS RIVER
D. R. AKIN A-2240
J. GILMORE A-2235
W. J. GILMORE A-1730
A. SPEED A-2296
A. SPEED A-2295
Tuloma Graham
2700
2650

Fig. 3A


MAP OF
SEWELL – EDDLEMAN AREA
YOUNG COUNTY, TEXAS
0 1000 2000 3000
FEET
CONTOURS ON TOP OF CADDO GRAY LIME
CONTOUR INTERVAL – 10 FEET
WELLS PRODUCING IN STRAWN SAND
WELLS PRODUCING IN CADDO LIME
WELLS PRODUCING IN MARBLE FALLS
WELL PRODUCING IN MARBLE FALLS & CHAPPEL LIME
M.F. TURNER A-1887
C.S. UPHAM A-1757
J.D. BURK A-2151
J.M. RODGERS
J.D. BURK A-2164
B.B.B.&C. R.R. NO.1 A-32
J.F. CLARK A-2200
J. CUNNINGHAM A-1720
S.S. BRAY A-1794
A.W. NABORS A-213
J. GATES
W. McDOWELL A-1620
R.M. BURTON A-6
IND. R.R. SUR. NO.1 A-156
W. McDOWELL A-1621
W.I. TIDWELL A-2022
Z.F. WOOD A-1763
JACOB MABEE A-186
J.E. PATTERSON A-220
R. HOTCHKISS A-147
A.G. WRIGHT A-2148
L.H. KIMBREL A-2190
F.M. DAVIS A-2213
J.M. BIRDWELL A-1588
S.M. HOLDERNESS A-1806
WM. WRIGHT A-2256
JOSEPH BIRDWELL A-1788
JAS. WILLESS A-1852
F.G. PAINE A-1516
EMILY KELLAM A-1782
TONEY FOWLER A-1427
W.A. CRUMPTON A-1381
Panhandle Kimbrell
MAJOR HULL
S. HOLDERNESS A-1803
-2500
-2550
-2600
-2650
-2700

FIG. 3B


UNION PROD CO
NO. I CHENEY
EL 1170
40
A.R. EPPENAUER
NO. 2 EDDLEMAN BROS
EL 1100
13
UNION PROD. CO
(A.R. EPPENAUER)
NO. I EDDLEMAN BROS
EL. 1177
12
UNION PROD. CO.
NO. I RAMSAY-CORLEY
EL 1201
41
UNION PROD CO
NO. I TRUE
EL 1213
42
HENRY ZWEIFEL
NO. I PARSONS
EL 1169
59
HENRY ZWEIFEL
NO. I-A SEWELL
EL. 1175
60
GROUP
SYSTEM
CISCO
CANYON
HOME CREEK LIMESTONE
PALO PINTO LIMESTONE
CAPPS LIMESTONE
SEA LEVEL
+1500
+1000
+ 500
- 500
-1000

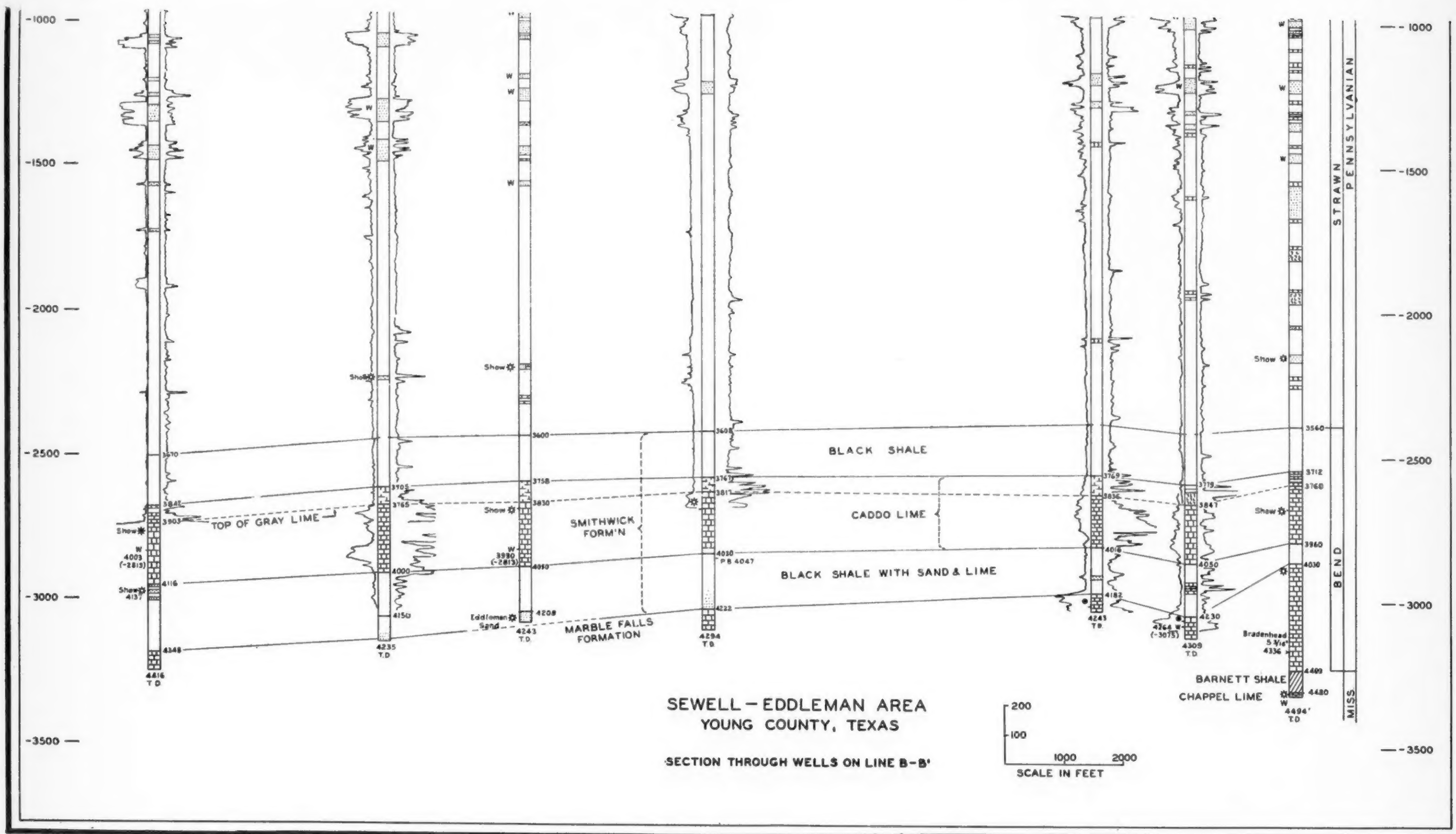

SEWELL – EDDLEMAN AREA
YOUNG COUNTY, TEXAS
SECTION THROUGH WELLS ON LINE B–B'
SCALE IN FEET
BLACK SHALE
CADDO LIME
BLACK SHALE WITH SAND & LIME
SMITHWICK FORM'N
MARBLE FALLS FORMATION
TOP OF GRAY LIME
BARNETT SHALE
CHAPPEL LIME
STRAWN
PENNSYLVANIAN
BEND
MISS
Eddleman Sand
Bradenhead

FIG. 4

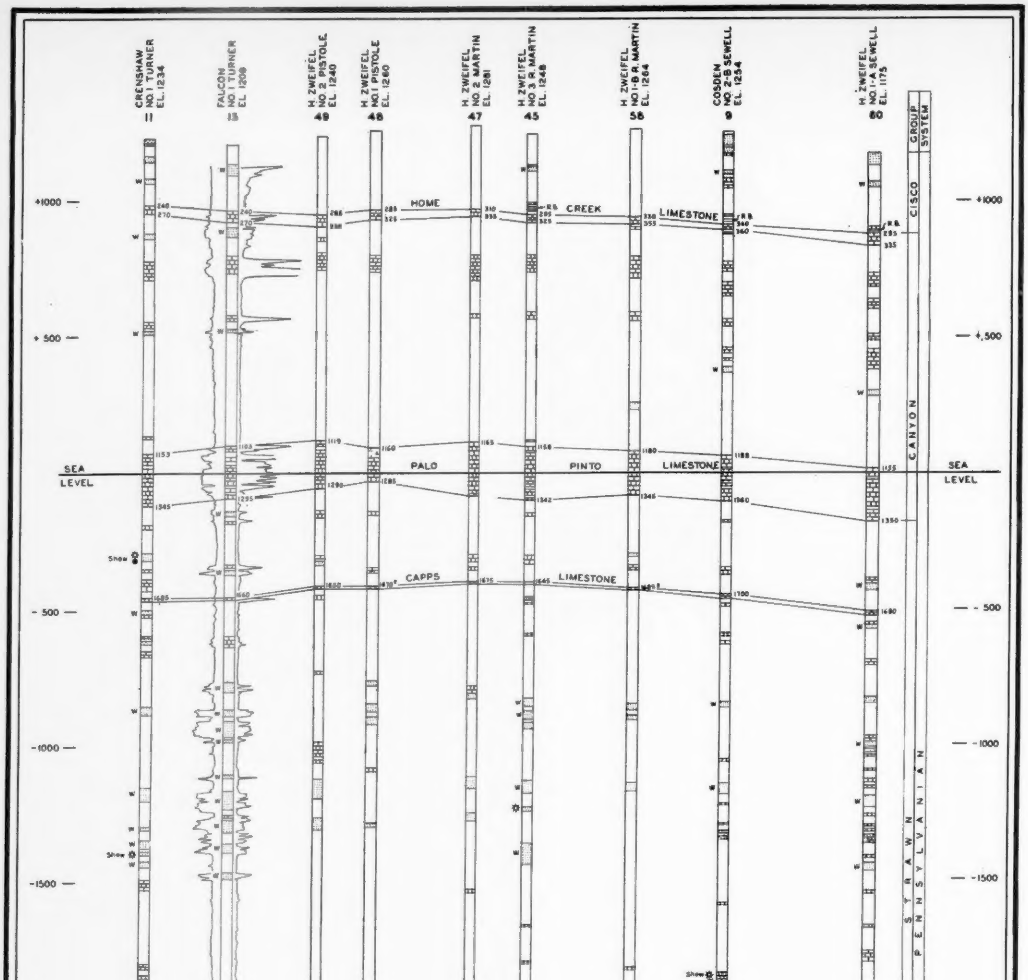

SEWELL — EDDLEMAN AREA
YOUNG COUNTY, TEXAS
SECTION THROUGH WELLS ON LINE C-C'
SCALE IN FEET
HOME CREEK LIMESTONE
PALO PINTO LIMESTONE
CAPPS LIMESTONE
SEA LEVEL
BLACK SHALE
TOP OF GRAY LIME
TOP OF SMITHWICK FORM'N
GRAY LIME
CADDO LIME
BLACK SHALE WITH SAND & LIME
MARBLE FALLS FORMATION
BARNETT SHALE
CHAPPEL LIMESTONE
ELLENBURGER LIMESTONE
CISCO
CANYON
STRAWN
BEND
PENNSYLVANIAN
MISS.
ORDOVICIAN
GROUP
SYSTEM
CRENSHAW NO.1 TURNER EL. 1234
FALCON NO.1 TURNER EL. 1208
H. ZWEIFEL NO.2 PISTOLE EL. 1240
H. ZWEIFEL NO.1 PISTOLE EL. 1260
H. ZWEIFEL NO.2 MARTIN EL. 1261
H. ZWEIFEL NO.3 R. MARTIN EL. 1248
H. ZWEIFEL NO.1-B R. MARTIN EL. 1264
COSDEN NO.2-B SEWELL EL. 1254
H. ZWEIFEL NO.1-A SEWELL EL. 1175

FIG. 5

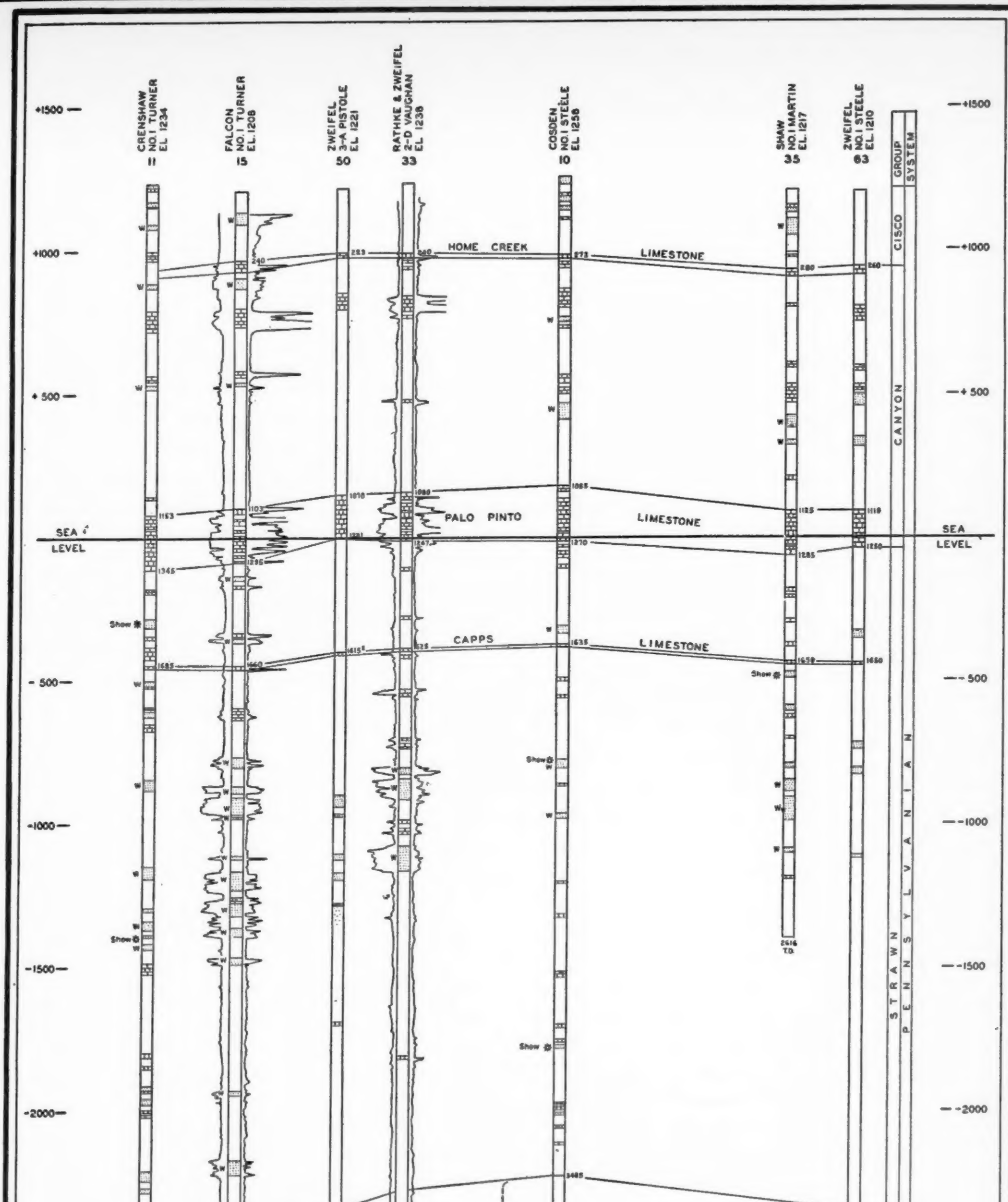

CRENSHAW NO. 1 TURNER EL. 1234
11
FALCON NO. 1 TURNER EL. 1208
15
ZWEIFEL 3-A PISTOLE EL. 1221
50
RATHKE & ZWEIFEL 2-D VAUGHAN EL. 1238
33
COSDEN NO. 1 STEELE EL. 1258
10
SHAW NO. 1 MARTIN EL. 1217
35
ZWEIFEL NO. 1 STEELE EL. 1210
63
GROUP
SYSTEM
CISCO
CANYON
STRAWN
BEND
PENNSYLVANIAN
+1500
+1000
+500
-500
-1000
-1500
-2000
-2500
-3000
HOME CREEK LIMESTONE
PALO PINTO LIMESTONE
SEA LEVEL
CAPPS LIMESTONE
BLACK SHALE
TOP OF GRAY LIME
CADDO LIME
SMITHWICK FORM'N
BLACK SHALE WITH SAND AND LIME
MARBLE FALLS FORMATION
Show
W
T.D.
SEWELL— EDDLEMAN AREA
YOUNG COUNTY, TEXAS
SECTION THROUGH WELLS ON LINE D-D'
200
100
1000
2000
SCALE IN FEET

FIG. 6

stone and the top of the Capps limestone. For the purposes of this article, the writers, lacking definite evidence for an unconformity in this area, have placed the lower limit of the Canyon series at the base of the Palo Pinto limestone.

Strawn group.—The Strawn group in this area is composed mainly of sandy shales and sandstones with a few scattered limestone members. The upper half of this group contains many thick beds of coarse-grained sandstone, but the lower half is composed of a monotonous succession of gray, sandy shales with a few sandstones. The Strawn is a great basin-filling series, and its thickness varies considerably from one area to another. In the Sewell-Eddleman area, the Strawn group has a thickness of 2,200–2,300 feet. Sellards[8] and most of the geologists who have worked in north-central Texas have long considered the base of the Strawn as coincident with the top of the Smithwick black shale. Cheney,[9] in his latest article, places the base of the Strawn at an unconformity at the "top of the Smithwick and related beds of the Lampasas series." Because there seems to be no serious disagreement about the base of the Strawn, the writers have, for practical purposes and in conformity with long usage, designated the base of this group as the top of the Smithwick black shale.

The Capps limestone, near the top of the Strawn group, is one of the most consistent and widespread formations in north-central Texas. Figure 2 is a subsurface contour map showing the structure of the Sewell-Eddleman area at the top of this member.

The "Rhodes" sand, a member of the Strawn group occurring about 800 feet below the Capps limestone, is a sporadic producing formation in the Sewell-Eddleman area (Fig. 1).

Bend group. Smithwick formation.—The Smithwick formation in the Sewell-Eddleman area is introduced by approximately 200 feet of soft, splintery shale, black for the most part, but with some irregularly spaced gray portions. Below this black shale is found a section of hard, black limestone with irregular breaks of black shale, which varies in thickness from about 25 to 60 feet. Underlying the broken black limestone and shale, the wells penetrate slightly more than 200 feet of gray, dark gray and brown, crystalline limestone, in places highly fossiliferous. The porous, pay zones found in this gray limestone, particularly the Sewell "pay," are in many places associated with these fossiliferous layers.

The top of this gray limestone section in most of the wells in the Sewell-Eddleman area has been determined from samples of well cuttings and checked in several places by electrical logs. The subsurface

[8] E. H. Sellards, *op. cit.*, p. 107.

[9] M. G. Cheney, *op. cit.*, p. 87.

structure of the area at the top of the gray limestone section is shown in Figure 3.

This entire black and gray limestone section described, popularly called the "Caddo lime," is one of the well known producing formations of north-central Texas. In the Sewell-Eddleman area, the gray limestone part of the Caddo has two distinct porous zones which produce oil and gas. The first zone, one of rather irregular porosity, is found directly at or close to the top of the gray limestone. Most of the wells encounter at least a showing of gas in this zone and several wells have yielded 10 million cubic feet. The second porous zone found in the gray limestone of the Caddo, and locally known as the "Sewell pay," is the principal producing zone in the Sewell field. This "pay" has been found consistently in wells in the Sewell field along the north flank and on the crest of the fold, occurring in most wells from about 100 to 140 feet below the top of the gray limestone. Wells drilled on the south flank of the fold have thus far failed to find this porous zone.

Below the Caddo limestone, the wells enter another predominantly black shale section, with irregular, thin lenses of fine-grained sand, sandy shale, and limestone, all containing a small amount of glauconite. In the lower part of this shale body, thin beds of green bentonitic shale are generally present. This black shale section varies in thickness from 75 feet to about 175 or 200 feet, depending on its relation to the structure, and being thinnest in the structurally high wells. At the base of this lower black shale, certain wells in the area encounter a thick, coarse-grained sandstone, here designated the "Eddleman" sand. This sand produced the gas in Eppenauer's Eddleman No. 1 (map No. 12), the discovery well in the Eddleman area and the first producer in the deeper beds.

The three-fold division of the Smithwick aforementioned forms a persistent and well recognized set of lithologic units that are particularly useful for subsurface mapping along the Bend flexure. These beds are considered by Sellards[10] and many other geologists as comprising the Smithwick formation of the Bend group.

Some of the more recent writers have discontinued the use of "Bend" as a group name, and Cheney[11] has designated the "Smithwick" and "Big Saline groups" as comprising his "Lampasas series," which supplants most of the upper part of the old Bend group. The producing sand in the Eddleman No. 1 (map No. 12), and the lower 50 or 75 feet of the black shale beds underlying the Caddo limestone, are part of the "Big Saline group" of Cheney. His "Smithwick group" includes that part of the "Lampasas series" above the "Big Saline group."

[10] E. H. Sellards, *op. cit.*, p. 101.

[11] M. G. Cheney, *op. cit.*, pp. 82–87.

Marble Falls formation.—In this area, the Marble Falls is represented in the upper part by brown limestone and black, spicular, in many places cherty limestone with some irregular, thin, black shale "breaks." This is followed by a dense gray limestone with a small percentage of shale in a few thin lenses. The total thickness of the beds assigned to the Marble Falls in the Sewell-Eddleman area is approximately 350 feet.

The Marble Falls limestone has developed porosity near its top south of the main axis of the structural feature in the Sewell-Eddleman area. This porosity has been found locally in a fossiliferous, coralline reef, but it generally occurs as honeycomb structure in the crystalline limestone.

MISSISSIPPIAN SYSTEM

Barnett shale.—In the Sewell-Eddleman area, the Barnett is represented by about 70 feet of dull, brownish black, "earthy" shale, thinly flaky in places, and here and there with a thin lens of black, muddy limestone containing shallow, brackish-water fossil material.

Chappel limestone.—The top of this formation is a light brown, porous, fossiliferous reef limestone, which is the lower pay zone (gas-distillate) in Henry Zweifel's Sewell No. 1-A (map No. 60), the discovery well in the deep "pays" in the Sewell field. In Zweifel's R. L. Martin No. 3 (map No. 45), this reef limestone, though present, was very thin and contained no showings of oil or gas.

The Martin No. 3 had a total thickness of 154 feet of Chappel limestone, the top 15 feet being a coarsely crystalline, white limestone containing a large quantity of crinoid-stem fragments, followed by 40 feet of light green, argillaceous limestone with at least 50 per cent bluish white chert, and the bottom 100 feet was white, crystalline, highly crinoidal, limestone.

Cosden's Steele No. 2-B (map No. 75) penetrated 122 feet of Chappel limestone lithologically similar to that described from Zweifel's Martin No. 3 except that none of the brown reef limestone was noted.

ORDOVICIAN SYSTEM

Ellenburger limestone.—The only wells to reach the Ellenburger limestone in the Sewell-Eddleman area are Henry Zweifel's R. L. Martin No. 3 (map No. 45) and Cosden Petroleum Corporation's Steele No. 2-B (map No. 75), already mentioned.

The R. L. Martin No. 3 penetrated 335 feet of finely granular, light brownish gray, dolomitic, non-fossiliferous limestone, with some layers of very dense, white lithographic limestone. No showings of free oil or gas were noted in the section of Ellenburger penetrated, although stains of oil and oil odors were common in the cuttings throughout the

last 75 feet drilled. Water was encountered at 5,002 feet, the total depth.

The Steele No. 2-B penetrated 41 feet of Ellenburger limestone between the depths of 4,504 and 4,545 feet, which section, when tested, produced flowing sulphur water.

SUMMARY OF PAY ZONES

Under the heading of "Stratigraphy," the pay zones of the Sewell-Eddleman area have been briefly mentioned. The important features in regard to the six producing zones encountered in wells in that area may be tabulated as follows.

Pay Zone	*Thickness (Feet)*	*Depth (Feet)*	*No. Wells*	*Remarks*
"Rhodes" sand Strawn	10–30	2,300–2,500	10	Lenticular sand. Production at present confined to north and east sides of Sewell field
Top zone of Caddo gray limestone Smithwick	10–20	3,700–3,850	3*	Irregularly porous zone. Contains gas throughout most of area
Sewell "pay," Caddo gray limestone Smithwick	5–30	3,850–4,000	35	Main "pay" in Sewell field. Porous zone 100–140 feet below top of gray limestone. Found in wells north of major axis
"Eddleman" sand	10–35	4,150–4,200	3	Locally restricted to Eddleman area
Marble Falls limestone	15–30	4,030–4,230	9	At present confined to area south of major axis
Chappel limestone Mississippian	10	4,480–4,490	1†	

* Map No. 19. Produces from both top zone and Sewell "pay" of Caddo limestone.
† Map No. 60. Produces from both Chappel and Marble Falls limestones.

SUBSURFACE STRUCTURE

The subsurface structural feature, included within the Sewell-Eddleman area, is near the north end of the northward-plunging Bend flexure. The beds below the Strawn on this part of the Bend flexure dip northward at the rate of approximately 20 feet per mile. Subsurface work reveals that superimposed on this regional dip, in the area under consideration, is a zone of pronounced folding with an east-west trend. In the case of most of the wells drilled here since 1937, cuttings have been analyzed, particularly of the formations ranging from the Caddo limestone to the Ellenburger, and electrical logs have been made of about a dozen wells.

The subsurface structure as mapped on both the Capps limestone of the Strawn (Fig. 2) and the top of the Caddo gray limestone (Fig.

TABLE OF WELL DATA

SEWELL-EDDLEMAN AREA, YOUNG COUNTY, TEXAS

(Elevations and depths in feet)

Map No.	Owner	Lease	Well No.	Date Completed	Elevation	Palo Pinto Limestone	Top, Capps Limestone	Top, Caddo Gray Limestone	Top, Marble Falls Limestone	Top, "Pay"	Total Depth	Remarks
1	Albright & Yorktex	W. E. Steele	1	6-11-37	1,269	1,095–1,300	1,635 (Est.)			Dry	2,600	Bottomed in Strawn
2	Brazos River Gas Co.	Higgins	1	5-16-31	1,222	1,041–1,250	1,630			Dry	3,359	Bottomed in Strawn
3	Frank Buttram	Holman	1	2-26-41	1,278	1,148–1,340	1,718	3,903		4,006	4,060	Oil well. Caddo limestone. Sewell "pay"
4	Carey & Carey	J. C. Vaughan	1	1-18-41	1,245	1,156–1,358	1,645	3,838		3,960	3,993	Oil well. Caddo limestone. Sewell "pay"
5	Carey & Carey	J. C. Vaughan	2	2- 7-41	1,228	?	1,615 (Est.)	3,774		3,890	3,914	Oil well. Caddo limestone. Sewell "pay"
6	Carey & Carey	J. C. Vaughan	3	March '41	1,241	1,085–1,271	?			2,474	2,480	Oil well. "Rhodes" sand. Strawn
7	Carey & Carey	J. C. Vaughan	4	4- 4-41	1,241	1,085–1,271		3,785	4,095	3,890?	4,108	Gas well. Caddo limestone. Sewell "pay"
65	Carey & Carey	J. C. Vaughan	5	May '41	1,238	1,148–1,315				2,489	2,502	Oil well. "Rhodes" sand. Strawn
8	Cosden Pet Corpn.	D. R. Sewell "B"	1	6-15-38	1,246	1,192–1,365	1,700	3,845		3,950	3,954	Oil well. Caddo limestone. Sewell "pay"
9	Cosden Pet. Corpn.	D. R. Sewell "B"	2	10- 5-39	1,254	1,188–1,360	1,700	3,813		3,947	3,961	Oil well. Caddo limestone. Sewell "pay"
10	Cosden Pet. Corpn.	W. E. Steele	1	2-29-40	1,258	1,085–1,270	1,635	3,732		3,849	3,911	Gas well. Caddo limestone. Sewell "pay"
11	N. B. Crenshaw	E. C. Turner	1	2- 3-33	1,234	1,153–1,345	1,685	3,945		Dry	4,050	Bottomed in Caddo limestone. Water at 4,047 (−2,813)
12	A. R. Eppenauer (Now Union Prod. Co.)	Eddleman Bros.	1	Feb. '37	1,177	1,171–1,360	1,710	3,830		4,208	4,243	Gas and distillate well "Eddleman" sand. Water in Caddo limestone 3,990 (−2,813)
13	A. R. Eppenauer	Eddleman Bros.	2		1,100	1,122–1,282	1,675	3,765	4,150		4,235	Incomplete, bottomed in Marble Falls limestone
14	A. R. Eppenauer	Hazelton	1	9-15-37	1,160	1,160–1,370	1,710	3,810	4,235	Dry	4,246	Bottomed in Marble Falls limestone
15	Falcon Co.	E. C. Turner Est.	1	3-10-41	1,208	1,103–1,295	1,660	3,898		Dry	4,006	Bottomed in Caddo limestone. Water at 4,006 (−2,798)
16	K. R. March *et al.*	Burton Est.	1	9- 9-40	1,184	1,135–1,325	1,665	3,825	4,248	Dry	4,513	Bottomed in Marble Falls limestone
17	Maynard & Talbot	J. C. Vaughan "A"	1	7- 2-39	1,282	1,202–1,353	1,710	3,868		3,985	3,988	Oil well. Caddo limestone. Sewell "pay"
18	Maynard & Talbot	J. C. Vaughan "A"	2	12- 9-39	1,247	1,170–1,340	1,687	3,867		4,004	4,012	Oil well. Caddo limestone. Sewell "pay"
19	Maynard & Talbot	J. C. Vaughan "A"	3	2-17-40	1,279	1,214–1,350	1,715	3,853		3,859–3,866 Gas	4,050	Gas well. top zone of Caddo
										3,966–? Oil		Oil well. Sewell "pay"
20	Maynard & Talbot	J. C. Vaughan "A"	4	4- 8-40	1,253	1,175–1,330	1,680	3,829		3,958	3,976	Oil well. Caddo limestone. Sewell "pay"
21	Maynard & Talbot	J. C. Vaughan "A"	5	5-13-40	1,256	1,157–1,330	1,681	3,855		3,989	4,002	Oil well. Caddo limestone. Sewell "pay"
22	Maynard & Talbot	J. C. Vaughan "A"	6	July '40	1,296	1,210–1,380	1,733	3,903		?	4,063	Oil well. Caddo limestone. Sewell "pay"
23	Maynard & Talbot	J. C. Vaughan "A"	7	9-22-40	1,255	1,160–1,332	1,683	3,865		3,989	4,001	Oil well. Caddo limestone. Sewell "pay"
24	Monroe Prod. Co.	Bridwell	1	3- 1-23	1,275	1,110–1,290	1,685	3,915	4,295	Dry	4,425	Bottomed in Marble Falls limestone
25	Monroe Prod. Co.	M. G. Cheney	1	2-13-25	1,191	1,195–1,360	1,735			Dry	3,005	Bottomed in Strawn
26	Monroe Prod. Co.	J. C. Vaughan	1	7-24-24	1,236	1,185–1,275	1,625			Dry	3,060	Bottomed in Strawn
27	Pace & Ward	M. G. Cheney	1	6- 2-27	1,167	1,190–1,395	1,735			Dry	2,803	Bottomed in Strawn
28	Panhandle O&R Co.	Bridwell	1	1-19-32	1,189	1,010–1,210	1,555			Dry	3,310	Bottomed in Strawn
29	Panhandle O&R Co.	Mary Cox	1	11-30-30	1,194	1,015–1,215	1,560			2,325	2,352	Oil well. "Rhodes" sand. Strawn
30	Panhandle O&R Co.	W. E. Steele	1	1930 or 1931	1,235	1,055–1,252	1,601			2,360	2,392	Oil well. "Rhodes" sand. Strawn
31	Rathke Oil Co.	Johnson	2	3-10-37	1,136	1,155–1,350	1,720	3,825 (Est.)		4,220	4,244	Oil well. "Eddleman" sand
32	Rathke & Zweifel	J. C. Vaughan "D"	1	7-23-40	1,238	1,065–1,260	1,606	3,732		3,834	3,872	Gas well. Caddo limestone. Sewell "pay"
33	Rathke & Zweifel	J. C. Vaughan "D"	2	3-22-41	1,238	1,080–1,247	1,620	3,760	4,020	3,840	4,087	Gas well. Caddo limestone. Sewell "pay"
34	Robert Oil Co.	Burke	1	4-23-28	1,306	1,150–1,350	1,725			Dry	2,501	Bottomed in Strawn
35	T. G. Shaw	Martin	1	4- 6-28	1,217	1,125–1,285	1,650			Dry	2,616	Bottomed in Strawn
36	T. G. Shaw	W. C. True	1	8- 4-28	1,172	1,105–1,275	1,655			Dry	3,310	Bottomed in Strawn
37	Texas Co.	Eddleman Bros.	1	1912	1,122	1,145–1,365	1,720			Dry	2,689	Bottomed in Strawn
38	S. A. Thompson	J. C. Vaughan	1	10- 3-39	1,282	1,235–1,402	1,765	3,934	4,245	2,548	4,342 P.B. 2,563	Bottomed in Marble Falls. Water at 4,335 (−3,053). Plugged back and producing from "Rhodes" sand. Strawn
39	S. A. Thompson	J. C. Vaughan	2	5-22-41	1,238	1,190–1,365	1,710	3,900	4,297	3,910	4,335	Oil well. Caddo limestone. Top zone
40	Union Prod. Co.	M. G. Cheney	1	Dec.? '38	1,190	1,212–1,380	1,753	3,903	4,348	Dry	4,416	Bottomed in Marble Falls limestone. Water in Caddo at 4,003 (−2,813)

TABLE OF WELL DATA—*Continued*

TABLE OF WELL DATA—*Continued*

Map No.	*Owner*	*Lease*	*Well No.*	*Date Completed*	*Elevation*	*Palo Pinto Limestone*	*Top, Capps Limestone*	*Top, Caddo Gray Limestone*	*Top, Marble Falls Limestone*	*Top, "Pay"*	*Total Depth*	*Remarks*
41	Union Prod. Co.	Ramsey-Corley	1	Aug. '38	1,201	1,185–1,370	1,707	3,817	4,222	3,817	4,294 P.B. 4,047	Gas well. Caddo limestone. Top zone
42	Union Prod. Co.	Elvira True	1	11-25-40	1,213	1,185–1,355	1,677	3,836	4,182	4,182	4,243	Oil well. Marble Falls limestone
43	Henry Zweifel *et al.*	R. L. Martin	1	12-29-38	1,270	1,188–1,342	1,689			2,508	2,515	Gas well. "Rhodes" sand. Strawn
44	Henry Zweifel *et al.*	R. L. Martin	2	10-27-39	1,270	1,170–1,353	1,680	3,850		3,956	4,000	Oil well. Caddo limestone. Sewell "pay'
45	Henry Zweifel *et al.*	R. L. Martin	3	5- 8-40	1,248	1,150–1,342	1,645	3,794	4,135	3,807 (Gas) 3,912–3,934 (Gas)	5,002 P.B. 3,998	Barnett shale, 4,453–4,513 Chappel limestone, 4,513–4,667 Ellenburger limestone, 4,667–5,002. Water, 5,002 (−3,754). Plugged back and completed as gas well in Caddo limestone
46	Henry Zweifel *et al.*	M. E. Martin	1	8-11-40	1,280	1,152–1,340	1,678	3,851		3,953	3,995	Oil well. Caddo limestone. Sewell "pay"
47	Henry Zweifel *et al.*	M. E. Martin	2	10-11-40	1,281	1,165–?	1,675	3,848		3,957	3,986	Oil well. Caddo limestone. Sewell "pay"
48	Henry Zweifel *et al.*	Mrs. L. D. Pistole "A"	1	7-18-40	1,260	1,160–1,285	1,670 (Est.)	3,872		3,990	4,003	Oil well. Caddo limestone. Sewell "pay"
49	Henry Zweifel *et al.*	Mrs. L. D. Pistole "A"	2	9-15-40	1,241	1,119–1,290	1,650	3,856		3,960	3,980	Oil well. Caddo limestone. Sewell "pay"
50	Henry Zweifel *et al.*	Mrs. L. D. Pistole "A"	3	11- 8-40	1,221	1,070–1,221	1,615 (Est.)	3,805		3,891	3,900	Oil well. Caddo limestone. Sewell "pay"
51	Henry Zweifel *et al.*	Mrs. L. D. Pistole "B"	1	12-12-40	1,236	1,087–1,290	1,637	3,815		3,923	3,953	Oil well. Caddo limestone. Sewell "pay'
52	Henry Zweifel *et al.*	D. R. Sewell "C"	1	2-28-39	1,253	1,180–1,355	1,700	3,827		3,924	3,960	Oil well. Caddo limestone. Sewell "pay"
53	Henry Zweifel *et al.*	D. R. Sewell "C"	2	7-27-39	1,245	1,166–1,350	1,700	3,847		3,961	3,984	Oil well. Caddo limestone. Sewell "pay"
54	Henry Zweifel *et al.*	D. R. Sewell "C"	3	9- 2-39	1,264	1,165–1,350	1,671	3,880		4,015	4,031	Oil well. Caddo limestone. Sewell "pay"
55	Henry Zweifel *et al.*	J. C. Vaughan "B"	1	6-23-39	1,272	1,202–1,370	1,710			2,505	2,539	Oil well. "Rhodes" sand. Strawn
56	Henry Zweifel *et al.*	J. C. Vaughan "B"	2	2-25-40	1,267	1,195–1,358	1,690	3,855		3,994	4,011	Oil well. Caddo limestone. Sewell "pay"
57	Cosden Pet. Corpn.	W. J. Jarnigan	1	3-21-41	1,177	1,168–1,340	1,650	3,815	4,175	4,192	4,235	Oil well. Marble Falls limestone
58	Cosden Pet. Corpn.	R. L. Martin "B"	1	4-29-40	1,264	1,180–1,345	1,685 (Est.)	3,857		3,996	4,008	Oil well. Caddo limestone. Sewell "pay"
59	Cosden Pet. Corpn.	S. W. Parsons	1	1-12-41	1,189	1,152–1,310	1,673	3,847	4,230	4,230	4,309 P.B. 4,244	Oil well. Marble Falls limestone. Water, 4,264 (−3,075)
60	Cosden Pet. Corpn.	D. R. Sewell "A"	1	8-15-37	1,175	1,155–1,350	1,680	3,760	4,030	4,030–4,060 (Gas) 4,480–4,490 (Gas & Oil)	4,494	Barnett shale, 4,403–4,480. Chappel limestone, 4,480–4,494. Water, 4,490 (−3,315). Gas well. Marble Falls limestone. Gas and oil. Chappel limestone
61	Cosden Pet. Corpn.	D. R. Sewell "A"	2	5- 3-39	1,226	1,148–1,348	1,685	3,833		3,905	3,935	Oil well. Caddo limestone. Sewell "pay" Water in Caddo at 3,932 (−2,706)
62	Henry Zweifel	D. R. Sewell "A"	3	8-28-39	1,209	1,170–1,320	1,685	3,756		3,831	3,842	Gas well. Caddo limestone. Sewell "pay"
64	Cosden Pet. Corpn.	D. R. Sewell "A"	4	5-30-41	1,206	1,170–1,295	1,650	3,821	4,180	4,192	4,257	Oil well. Marble Falls limestone
63	Cosden Pet. Corpn.	W. E. Steele "B"	1	2- 4-41	1,210	1,119–1,250	1,650	3,810?	4,150	4,200?	4,255	Oil well. Marble Falls limestone
66	Henry Zweifel *et al.*	M. E. Martin	3	7-21-41	1,243	1,184–1,340	1,625			2,491	2,518	Oil well. "Rhodes" sand. Strawn
67	Henry Zweifel *et al.*	M. E. Martin	4	8-13-41	1,255	1,135–1,305	1,652	3,766		3,918	3,976	Oil well. Caddo limestone. Below Sewell "pay"
68	Henry Zweifel *et al.*	M. E. Martin	5	10- 2-41	1,260	1,152–1,328	1,657			2,503	2,507	Oil well. "Rhodes" sand. Strawn
69	Henry Zweifel *et al.*	M. E. Martin "B"	1	9-20-41	1,218	1,110–1,305	1,605	3,740	4,016	4,053	4,069	Gas well. Marble Falls limestone
70	Henry Zweifel *et al.*	Mrs. L. D. Pistole "B"	2	8-24-41	1,265	1,095–1,285	1,675	3,838		3,939	3,962	Oil well. Caddo limestone. Sewell "pay"
71	Henry Zweifel *et al.*	Mrs. L. D. Pistole "B"	3	9- 5-41	1,265	1,128–1,345	1,690	3,870		3,980	4,003	Oil well. Caddo limestone. Sewell "pay"
72	Henry Zweifel *et al.*	D. R. Sewell "C"	4	9- 4-41	1,224	1,140–1,315	1,680	3,842	4,216	4,200	4,257	Oil well. "Eddleman" sand
73	Henry Zweifel *et al.*	D. R. Sewell "C"	5	9-24-41	1,267	1,178–1,346				2,530	2,535	Oil well. "Rhodes" sand. Strawn
74	Cosden Pet. Corpn.	D. R. Sewell "A"	5	10- 6-41	1,210	1,210–1,400	1,718	3,842	4,168	4,168	4,223	Oil well. Marble Falls limestone
75	Cosden Pet. Corpn.	W. E. Steele "B"	2	7-18-41	1,234	1,120–1,275	1,627	3,754	4,023	3,890	4,545	Barnett shale, 4,320–4,382. Chappel ls., 4,382–4,504. Ellenburger, 4,504–4,545. Sulphur water, P.B. 3,968. Compl., gas well in Caddo
76	Henry Zweifel	P. K. Deats	1	10-15-41	1,203	1,110–1,315	1,643	3,920	4,403	4,265	4,535	Oil well
77	McLester	J. F. Hall	1	8- 4-41	1,136	1,105–1,330	1,668	3,875	4,355	Dry	4,370	Bottomed in Marble Falls limeston

3) is an anticlinal fold whose major axis trends nearly east and west. The structure as mapped on the Capps limestone conforms in its general aspects with that mapped on the Caddo gray limestone, but the folding on the latter formation is about twice as steep as that shown on the Capps limestone, and it shows a greater amount of structural detail. The increase in amount of folding noted in the Caddo as compared with the Capps limestone is believed, from the meager evidence available, to continue with even greater intensity into the Marble Falls and older beds.

In addition to the main east-west folding, there appears to have been developed in the Caddo limestone a series of secondary folds. These lesser folds control, to some extent, the accumulation of oil and gas.

In the Sewell field, particularly, where most of the drilling has been done, it is noted that wells with a Caddo gray limestone datum of −2,550 and above produce gas or gas-distillate in the Sewell "pay," while those wells below this critical contour are primarily oil wells. Several wells with a gray limestone datum of −2,650 or more have encountered water in the Sewell "pay."

DEVELOPMENT PRACTICES

All early wells in the area were drilled with standard tools, but more recently, most of these have been replaced with rotary equipment. Drilling-in may be done with either cable tools or rotary. In the latter case, electrical logs and gun-perforating are effective aids to the proper completion of the wells.

Although most of the wells have been completed as natural producers, those which have been acidized indicate that both the Caddo and the Marble Falls producing zones respond well to acid treatment.

The average density of wells in the Sewell field is now about one well to 35 acres.

MARKETING FACILITIES

A ready market for the desirable quality of oil produced in the Sewell-Eddleman area is furnished by the facilities of The Texas Company pipe line, the Cosden Petroleum Corporation refinery located in the field, and the Gratex refinery at Graham. The market for gas is provided by the lines of the United Gas Company, the Brazos River Gas Company, and the Lone Star Gas Company.

TABLE OF WELL DATA

The accompanying table (pp. 215–216) shows the principal facts pertaining to each well drilled in the Sewell-Eddleman area.

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RHYTHM OF PERMIAN SEAS—A PALEOGEOGRAPHIC STUDY[1]

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ABSTRACT

Since the writer believes that an understanding of the physical history of the Permian period is fundamental to a sound classification of the rocks of this system, he has attempted to summarize the physical history of the Permian of the southern Mid-Continent with especial reference to the West Texas Permian basin. To this end seven paleogeographic maps are presented, drawn on the following horizons: latest Pennsylvanian (Thrifty), Wolfcamp (Coleman Junction), lower Leonard (Choza), San Andres (Blaine), middle Guadalupe (Grayburg), Castile and Salado, and Rustler. The regional correlations involved in making these maps are discussed in the text, and several supporting cross sections are illustrated. Some of the more prominent features of these maps are pointed out.

From the data on the areal extent of the seas, several curves have been constructed which show graphically many features of Permian history and throw much light on the physical basis for the classification of the rocks of this system. The text summarizes the history of the Permian in the southern Mid-Continent, and points out the relation of this study to the standard Permian section for North America set up by Adams *et al.*

The Wolfcamp epoch was initiated by the cessation of the Marathon-Arbuckle orogeny and the resultant constriction of the seas. This epoch was closed and the Leonard begun by the restriction of marine circulation and the beginning of large-scale evaporite deposition. These restricted seas are divided into marine, including the normal marine and vitasaline zones of Lang; saline, including Lang's penesaline, saline, and supersaline zones; and the brackish, including his brackish and fresh zones. The Leonard epoch ended with the retreat of the seas into the Delaware basin at the close of San Andres time. The Guadalupe was the epoch of reef-making and was brought to a close by the death of its greatest reef, the Capitan. The Ochoa commenced with a saline sea confined to the Delaware basin, and this epoch of restricted, highly saline seas was ended by the final Permian uplift which covered the evaporites with a blanket of red sands and shales.

This paper is an outgrowth of numerous discussions leading to the publication of the "Standard Permian Section of North America."[3] It is an attempt to present the physical history of the Permian upon which this classification is based.

While most of the information in this paper comes from the writer's own interpretation of original sample logs, he is indebted to numerous individuals and companies for information, especially concerning Kansas and Oklahoma. In a work of this character it is rather difficult to give due acknowledgment to all the persons who have made contributions. Most of the ideas have been amplified and clarified by the criticism of numerous individuals, chief of whom are John Emery Adams, W. D. Anderson, R. K. DeFord, A. R. Denison, R. I. Dickey,

[1] Read before the West Texas Geological Society, February 21, 1939, the New Mexico Geological Society, June 14, 1939, and the Panhandle Geological Society, November 24, 1939. Manuscript received, October 8, 1941.

[2] Consulting geologist.

[3] John Emery Adams *et al.*, "Standard Permian Section of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1673–81.

John L. Ferguson, P. B. King, R. E. King, E. Russell Lloyd, Robert Roth, Dana M. Secor, and John W. Skinner. The writer is also indebted to Leslie Page for much of the drafting.

Basis of Geologic Classification

Possibly the most widely used method of classification and correlation is the paleontologic. This method is easily applied in isolated areas of marine sedimentary rocks containing faunas already described from other known sections. In many cases it is the only way of dating such strata satisfactorily. Where organisms having distinct evolutionary characters, such as the graptolites, ammonoids, and fusulines are abundant, the paleontologic method in regional and world-wide correlation is amazingly accurate.

There are, however, certain limitations to the paleontologic method which must be borne in mind. The evolution of different groups of organisms did not proceed at the same rate and their migration to different parts of the world was not always at the same speed. The evidence from each of several fossil groups must thus be checked against that from the others, and in case of conflict, physical evidence may have to be used to reconcile the differences. Facies differences also may give trouble, especially where the fauna has not been studied in detail. Many faunal assemblages are characteristic of one sedimentary facies, and similar assemblages may occur at several different horizons. While careful work usually reveals significant evolutionary differences between these recurrent faunas, in relatively unknown fossil groups, there is danger of correlating depositional conditions rather than horizons of contemporaneous deposition.

There is, however, another and more fundamental basis for geologic classification. This is the diastrophic or physical method, which relies on movements of the earth's crust and accompanying changes in climate and sedimentation. There is no question that these changes reflect the major events in the history of the earth and give meaning to the great lithologic breaks in the geologic column. Since climatic and geographic conditions are the major factors controlling the rate of evolution of organisms, the physical history of the earth also is reflected in the evolutionary history of its organisms.

In this connection, Lee's introductory remarks[4] in his paper on Mesozoic paleogeography are particularly appropriate.

> The stratigraphic geologist has become so accustomed to relying on the paleontologist for correlations that he is apt to reject without due consideration any suggestions which seem to be at variance with that derived from

[4] W. T. Lee, "Early Mesozoic Physiography of the Southern Rocky Mountains," *Smithsonian Misc. Coll.*, Vol. 69, No. 2 (1918), p. 2.

fossils. There is no conflict when all the facts are known and I am convinced that physiographic principles can be used to great advantage in correlating some of the unfossiliferous sedimentary rocks in the mountain region.

The diastrophic method of classification is open to the great objection that, although the earth has undergone a number of great periods of unrest, not all are equally well represented throughout the world nor are all the movements of one period exactly contemporaneous in different provinces. In one region or geologic province, however, nearly contemporaneous movements may be traced. For world-wide correlation this method is considerably less exact than the paleontologic method.

The problem of classification is, of course, complicated by the fact that during the greatest disturbances in the earth's history, sedimentation was going on at some place on its surface. This results in passage beds between groups, series, systems, and even between the rocks of the different eras. Wherever these passage beds are discovered there must always arise the question of where to draw the dividing line in that locality, and the solution must be either a paleontologic one, if suitable fossils can be found, or, failing that, an arbitrary one based principally on convenience.

In spite of these practical disadvantages inherent in the diastrophic method in classification, the writer feels that a classification of the Permian or any other period must have a sound physical background to survive.

Paleogeographic Maps

The physical background of the Permian system in the southern Mid-Continent is presented by means of a series of seven paleogeographic maps drawn at key horizons. These show the extent of the seas and such generalized land features as the chief highland areas and mountain ranges. These maps have been compiled from published and unpublished surface and subsurface information. In the correlation chart (Fig. 1), heavy-dashed lines indicate the horizons on which the maps are drawn. This chart follows very closely the one published by DeFord and Lloyd,[5] as to the West Texas Permian basin, but free use has been made of other published material.[6]

[5] Ronald K. DeFord and E. Russell Lloyd, "West Texas-New Mexico Symposium, Part 1, Editorial Introduction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), Fig. 2.

[6] C. O. Dunbar, "The Type Permian: Its Classification and Correlation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 2 (February, 1940), Fig. 9.

C. L. Mohr, "Subsurface Cross Section from Texas to Nebraska," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), pp. 1694–1711.

G. H. Norton, "Permian Redbeds of Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939), pp. 1751–1819.

R. C. Moore, "Stratigraphy of Kansas," *Oil and Gas Journal*, Vol. 39, No. 7 (June 27, 1940), p. 74.

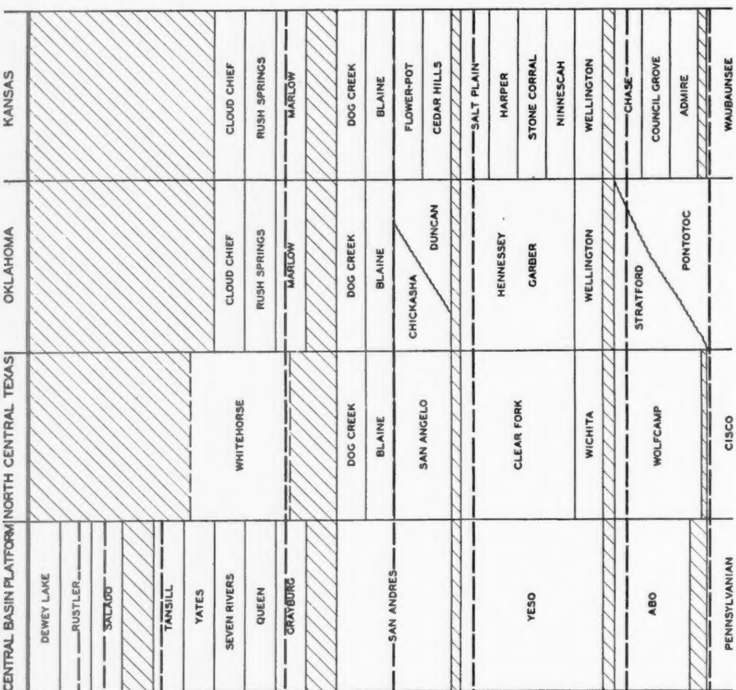


FIG. 1.—Simplified correlation chart for southern Mid-Continent. Heavy dashed lines indicate horizons of maps.

While most of the subsurface data on which these maps are based are, of course, unpublished, the accompanying cross sections illustrate certain critical or controversial correlations which will be pointed out under the appropriate headings. In addition, several cross sections have been published in connection with the West Texas-New Mexico symposium[7] which illustrate many of the points touched upon in this paper. Another east-west cross section of the Permian basin has been prepared by the West Texas Geological Society.[8] Probably most comprehensive of all published subsurface data are the stereograms of F. E. Lewis.[9] While the writer disagrees with some of Lewis' correlations, as will be pointed out in another portion of this paper, there is no doubt that his stereograms represent an important compilation of subsurface information which should be studied in connection with any paleogeographic discussion.

In spite of the large number of subsurface data on which these paleogeographic maps are based, the reader must realize that the maps, together with this paper, are an interpretation of the basic evidence and make no claim to final accuracy. To enter into detailed discussion of subsurface and surface correlations would only obscure the broad regional relationships which it is intended to point out. Current drilling will no doubt clear up many doubtful points and change many stratigraphic details, but it is probable that the broad outlines of Permian paleogeography are fairly well established.

LATEST PENNSYLVANIAN TIME

The first map (Fig. 2) is intended to represent conditions at about the transition point between the Pennsylvanian and Permian time. In this paper the base of the Permian is considered to lie at the base of the Wolfcamp series.[10] The question as to the proper placing of the base of the Permian has been discussed very fully by Dunbar, Cheney, Moore, and the Association subcommittee on the Permian,[11] so that

[7] For the location of these sections and the names of the authors see Fig. 3, "West Texas-New Mexico Symposium, Editorial Introduction," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 12.

[8] Now in course of publication by the Geological Society of America.

[9] F. E. Lewis, "Position of San Andres Group, West Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 1 (January, 1941), pp. 73–103.

[10] J. E. Adams *et al.*, "Standard Permian Section of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), p. 1674.

[11] C. O. Dunbar, *op. cit.*, pp. 273–80.
M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 94–95.
R. C. Moore, "Carboniferous-Permian Boundary," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 2 (February, 1940), pp. 282–336.
C. W. Tomlinson *et al.*, "Classification of Permian Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 2 (February, 1940), pp. 353–54.

it seems hardly necessary to recapitulate here. Suffice it to say that in the West Texas Permian basin, the physical evidence definitely indicates that the Wolfcamp series belongs with the overlying Permian rocks rather than with the underlying Pennsylvanian.

Therefore, Figure 2 has been drawn on a horizon in the *Triticites* zone corresponding with the Obregon formation of the Thrifty group as defined by Cheney.[12] As indicated on the correlation chart, this horizon falls just above the Gaptank of the Marathon region, above the Magdalena of New Mexico, in the Pontotoc of Oklahoma, and in the uppermost Wabaunsee of Kansas.

The geography at the close of the Pennsylvanian was constituted as one would expect at the end of an epoch of extensive orogeny such as the Arbuckle-Marathon orogeny.[13] The major positive areas around the margins of the seas stood as highlands, reaching mountainous proportions in most places. On the southeast these mountains occupied the site of the former Llanoria, Ouachita, and Marathon geosynclines.[14] These geosynclines had existed since early Paleozoic time but the rocks in them were folded and uplifted by the Marathon-Arbuckle orogeny.

In south-central Oklahoma, the southeast end of the Anadarko-Ardmore geosyncline[15] was compressed into a narrow deep trough which connected the northern marine area of Oklahoma and Kansas with the southern area through the Red River country of Texas. It is probable that the Ouachita Mountain region was low at this time, for, as noted by van der Gracht,[16] the Ouachitas do not seem to have been an important source of Pontotoc sediments. The sandstones and shales of this age in Montague County, Texas, most probably came from the Wichita uplift. It is possible that sand bars and spits developed at the entrance to this strait and formed the lagoons which were the sites of the swamps in which the Newcastle coals of Young County were formed.

The Arbuckle uplift of southern Oklahoma finds its westward continuation in the Amarillo mountains of the Texas Panhandle.[17]

[12] M. G. Cheney, *op. cit.*, pp. 90–91.

[13] W. A. J. M. van Waterschoot van der Gracht, "Permo-Carboniferous Orogeny in South-Central United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 1012–14.
P. B. King, "Geology of the Marathon Region, Texas," *U. S. Geol. Survey Prof. Paper 187* (1937), p. 86.

[14] E. H. Sellards, "Geology of Texas," *Univ. Texas Bull. 3232* (1932), pp. 128–29.

[15] E. A. Paschal, "Major Tectonic Provinces of Southern Oklahoma and Their Relation to Oil and Gas Fields," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 1 (January, 1941), pp. 9–10.
W. A. J. M. van Waterschoot van der Gracht, *op. cit.*, p. 1013.

[16] W. A. J. M. van Waterschoot van der Gracht, *op. cit.*, p. 1027.

[17] Sidney Powers, "Age of Folding of Oklahoma Mountains," *Bull. Geol. Soc. America*, Vol. 39, No. 4 (December, 1928), p. 1062.

These mountains formed an elongate island in latest Pennsylvanian time whose outline has been traced from the maps and sections of Rogatz[18] together with some additional well logs. From this work it appears that there may have been a shallow passage between the Wichitas and the Amarillo mountains, and a deeper one through the Dalhart basin on the west which separated the Amarillo mountains from the Bravo uplift and the Sierra Grande of New Mexico and Colorado.

The shore line of southwestern Kansas and the Oklahoma Panhandle has been drawn largely from data given by Rogatz[19] and Hemsell[20] and indicates the westernmost extent of late Pennsylvanian marine rocks. Farther west, beds of this age, if present at all, are represented by the presumably continental deposits of the Sangre de Cristo conglomerate.[21]

Information on the location of the shore line in New Mexico is rather meager. However, a deep well, Navajo's McAdoo No. 1, in southeastern DeBaca County, encountered beds of the upper *Triticites* zone, and the same beds seem to be present in a deep well in southwestern Chaves County, The Texas Company's Wilson No. 1. Needham has reported rocks containing uppermost Pennsylvanian fusulines from the Sacramento Mountains in northeastern Otero County, which would seem to prove the existence of a seaway here in latest Pennsylvanian time.[22]

At the same time, northern New Mexico seems to have been occupied by a mountainous highland, largely composed of pre-Cambrian crystalline rocks. This was part of the ancestral Rockies[23] and is well known from borings in the northeastern part of the state and from outcrops in the Pedernales uplift on the southwest. Some of the peaks in this highland must have been hundreds of feet high, as they were not covered by marine sediments until the close of Yeso time. Well logs make it apparent that this uplift was closely related to that of the Amarillo mountains.

The importance of this great positive element of northern New Mexico can hardly be overemphasized. It is the dominant influence in the history of the west side of the Permian basin and is rivaled in

[18] Henry Rogatz, "Geology of Texas Panhandle Oil and Gas Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (July, 1939), pp. 983–1053.

[19] Henry Rogatz, *op. cit.*, Fig. 19.

[20] Clenon C. Hemsell, "Geology of Hugoton Gas Field of Southwestern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (July, 1939), pp. 1054–67.

[21] F. A. Melton, *Jour. Geol.*, Vol. 33 (1925), pp. 807–15.

[22] C. E. Needham, "Correlation of Pennsylvanian Rocks of New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 178.

[23] Ronald K. DeFord and E. Russell Lloyd, *op. cit.*, Fig. 1.

regional importance only by the Llanoria geosyncline on the southeast.

In another geologic province farther south, two wells drilled on the northern part of the Diablo platform in southern Otero County, New Mexico, Turner's Everett No. 1 and Hearte-Paso's Evans No. 1, encountered Mississippian below Wolfcamp, indicating a considerable land mass here in later Pennsylvanian time. This conclusion is borne out by the record of a deep well, the California Company's University-Theissen No. 1, in northern Hudspeth County, Texas, which also encountered Mississippian underlying Wolfcamp beds, and King reports the Pennsylvanian largely missing from the surface of the same region.[24]

Apparently the shore line must have been very close to the present eastern edge of the Diablo platform, as the Anderson-Prichard's Borders well No. 1 in the western face of the Delaware Mountains in western Culberson County found the *Triticites* zone of the upper Pennsylvanian underlying shales and limestones carrying Wolfcamp fossils.

In Jeff Davis County the lower Permian and upper Pennsylvanian rocks are covered by a blanket of thick Cretaceous sedimentary rocks and Tertiary lavas. Thus, the shore line here can be drawn only by inference and is somewhat uncertain.

In the Glass Mountain region of northern Brewster County, King[25] has shown that there is a strong unconformity below the basal Permian in the southwestern part of the mountains. This unconformity decreases in importance farther northwest, near the Pecos County line. Even here, however, beds of upper Thrifty age are apparently missing, although the stratigraphic sequence is nearly complete through the upper Pennsylvanian and lower Permian. Therefore, the shore line has been drawn a short distance north of the Glass Mountains. The interpretation given on the map shows a seaway over the present outcrop of the Alta formation of the Chinati Mountains in western Presidio County. No fossils have been found in this formation,[26] but since there is no physical evidence of a break in this part of the section, it is possible that a seaway extended southwest through this region.

West of the Glass Mountains, in extreme southern Pecos County and central Terrell County, information is meager. In extreme eastern Terrell County a deep well, the Ohio Oil Company's Goode No. 1,

[24] P. B. King, "Permian Stratigraphy of Trans-Pecos Texas," *Bull. Geol. Soc. America*, Vol. 45, No. 4 (August, 1934), pp. 742–43.

[25] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, pp. 82, 83.

[26] J. W. Skinner, "Upper Paleozoic Section of Chinati Mountains, Presidio County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 182, 185–86.

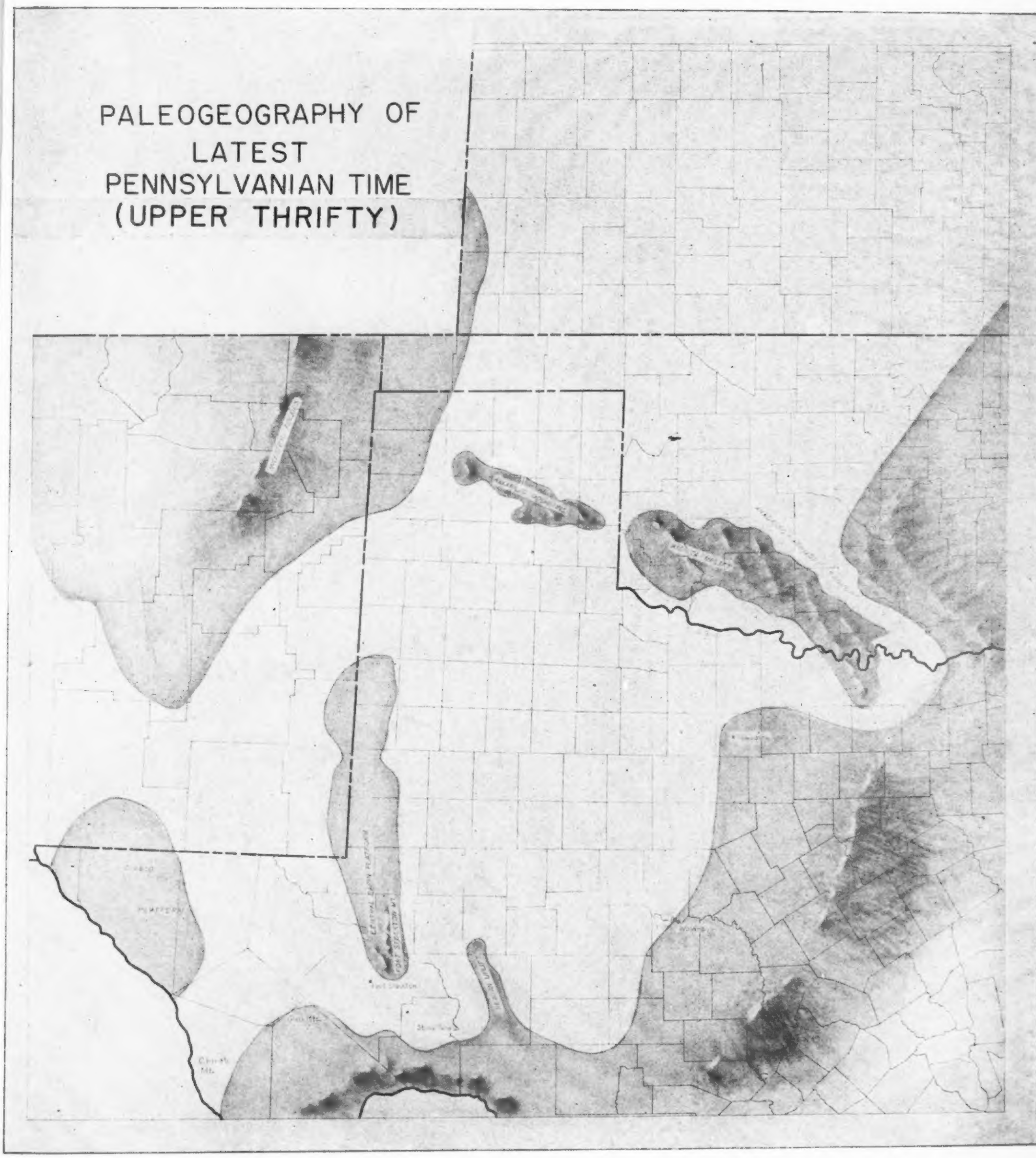


FIG. 2.—Notice strong relief of: Ancestral Rockies in northeastern New Mexico (upper left part of area of this map); Amarillo mountains in Texas Panhandle; Wichita uplift in southwestern Oklahoma (separated from Hunton arch on east by Anadarko-Ardmore trough); Llanoria land mass in central and southwestern Texas; and Fort Stockton mountains in southern part of Central Basin platform (West Texas).

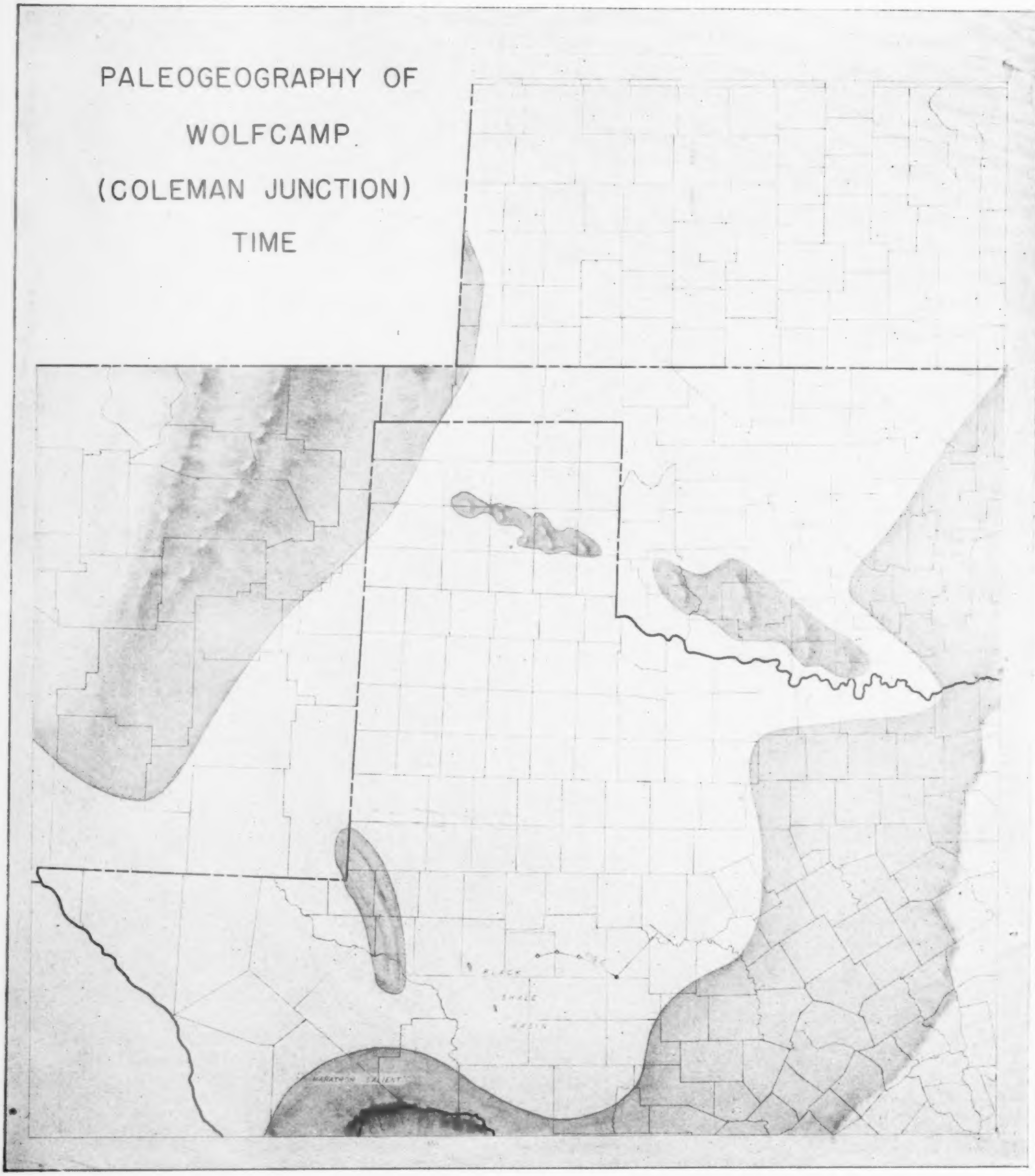


Fig. 3.—Line of cross section (Fig. 6) is on east side of black shale basin (south-central part of area of this map), showing location of wells used in cross section. Notice decrease in elevation of land and slight increase in elevation of sea.

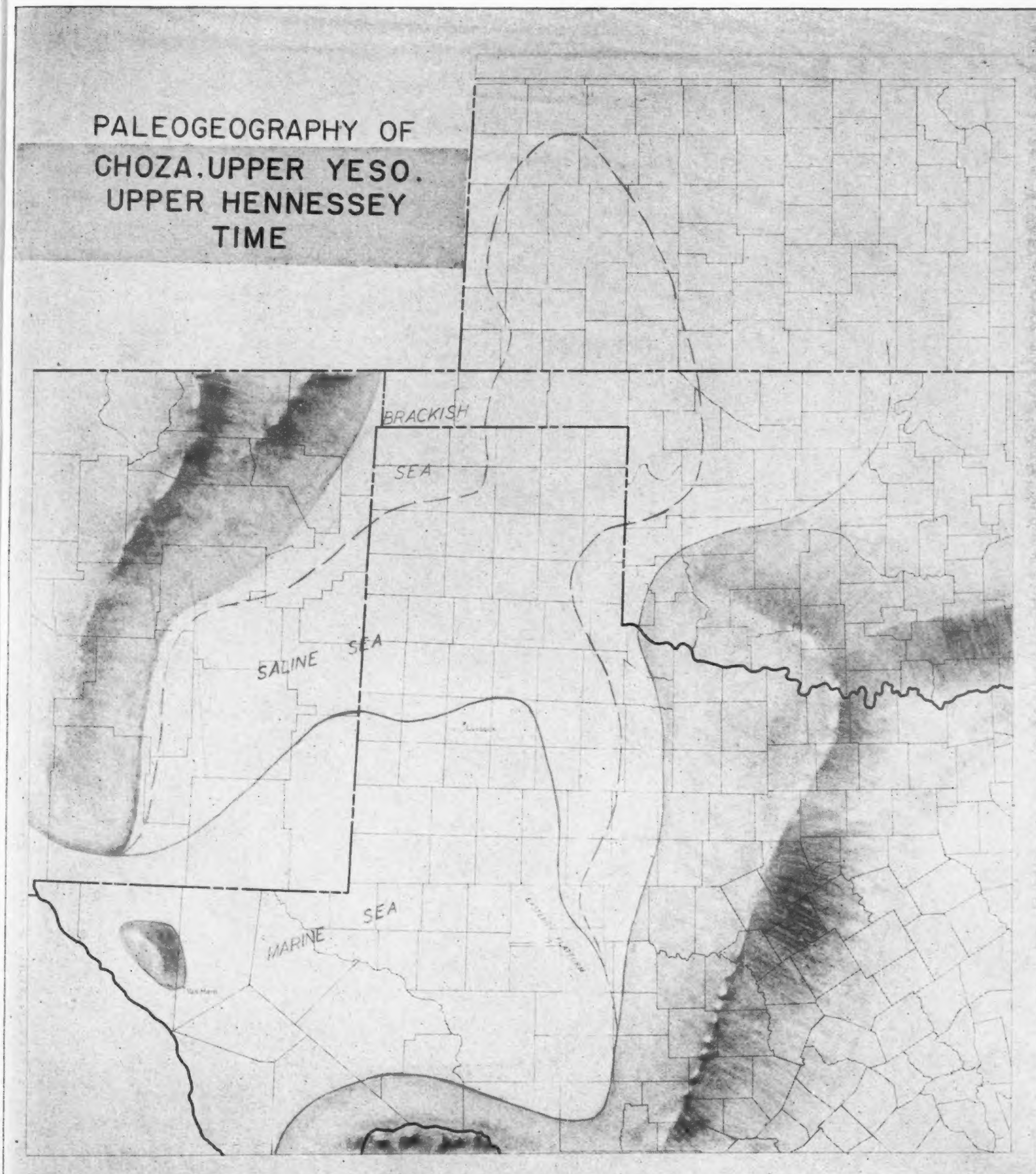


FIG. 4.—Map shows beginning of evaporite deposition. Notice lands are low, and seas completely cover sites of Amarillo and Fort Stockton mountains. Ardmore trough has been closed by beginning of Ouachita rejuvenation.

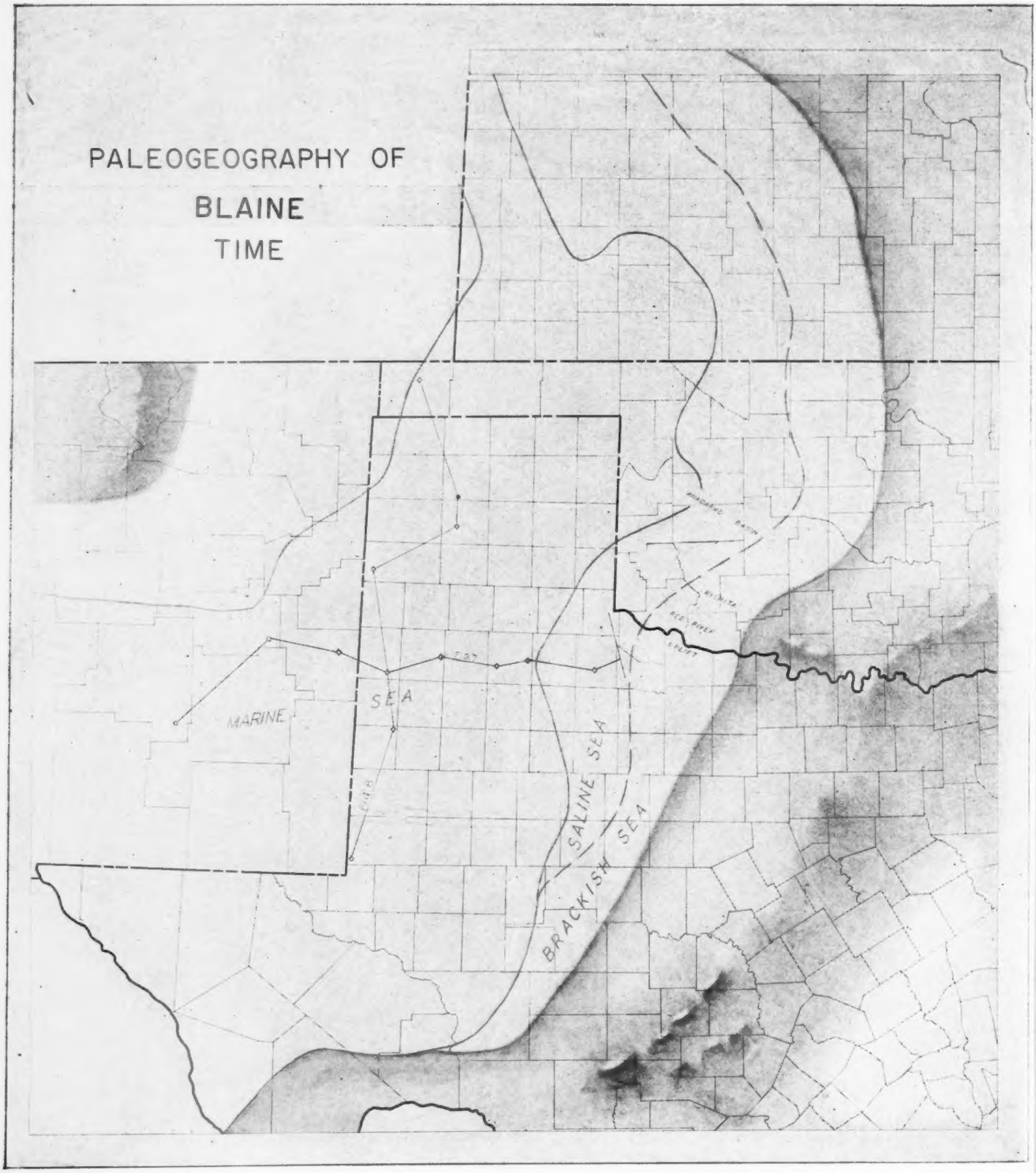


FIG. 5.—Lines of cross sections with location of wells (Figs. 7 and 8) shown in west-central part of area of this map. Notice low lands and widespread seas with northwest entrance to Permian basin.

drilled in Stone Bend of Pecos River, encountered a black shale section which extended below 9,000 feet with no evidence of a Pennsylvanian-Permian break. On the other hand, in a well about 15 miles south, Milham's Bassett No. 1, Ordovician fossils are reported from a relatively shallow depth. Still farther south, in southern Terrell and Val Verde counties, metamorphic and overthrust rocks have been found underlying Cretaceous strata in many wells.[27] Thus, the northern boundary of the buried portion of the Marathon folds is fairly well known, and by analogy with the exposed portion the ancient shore line can be determined rather closely.

In the Todd area of central Crockett County and the Big Lake field of southern Reagan County the lower Permian Wolfcamp rests directly on limestone of lower Pennsylvanian age. Therefore, a peninsula is shown extending northward into this area. Its exact boundaries are uncertain, since the Pennsylvanian rocks of this region are sparsely fossiliferous black shales, making it difficult to determine whether upper Pennsylvanian rocks are present in wells drilled off the crest of the Reagan uplift.

Farther southeast, in Sutton, Edwards, and Kimble counties, the shore line must be inferred from very little evidence, as pre-Cretaceous erosion has removed most of the rocks of this age. The subsurface evidence consists of lensing sandstone beds in the lower Permian and upper Pennsylvanian in eastern Schleicher County and in the Holman area of Sutton and Edwards counties, which may indicate that the shore line lay not far to the south and east.

On the east side of the basin it is apparent from Cheney's cross sections and discussion[28] that the shore line lay not far from the present outcrops, since the Newcastle-Waldrip coals must have been formed in low lands probably not far from the sea.

In the central part of the West Texas basin, extending northward from central Pecos County at least to central Gaines County, lay a mountainous island occupying approximately the site of the subsurface feature now known as the Central Basin platform.[29] That at least the southern part of this area was above sea-level during latest Pennsylvanian and early Permian time is known from deep wells

[27] E. H. Sellards, *op. cit.*, pp. 136–40.
West Texas Geological Society, "Possible Future Oil Provinces of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 8 (August, 1941), p. 1530.

[28] M. G. Cheney, *op. cit.*, Fig. 2, p. 91.

[29] Lon D. Cartwright, Jr., "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 969–75.

drilled in western Crane[30] and northern Pecos counties, but the outline shown is largely inferred from known Permian structure.[31] These mountains seem to be the northward continuation of the Paleozoic positive axis in the eastern part of the Coahuila peninsula[32] and probably were related to the salient of the Marathon folds in southern Pecos and northern Terrell counties. The southern portion of these mountains in northern Pecos County seems to have been higher and have suffered more erosion than the northern extension in Crane County. In several places the pre-Cambrian crystallines were exposed (notably at the site of the Apco pool), and isolated peaks of lower Paleozoic rocks were emergent well into Leonard time. It is proposed here to call this southern portion of the uplift the Fort Stockton mountains, since they were discovered by the Roxana-Kirby's University No. 1, located about 10 miles northeast of the town of Fort Stockton on the crest of the feature known as the Fort Stockton "high."[33] This well encountered granite (presumably pre-Cambrian) at a depth of 4,750 feet.

Future drilling may prove that the Fort Stockton mountains form part of a more or less continuous backbone of the Central Basin platform, or it may be that the older structures form a series of separate uplifts which should receive separate names.

In summary, while the lands were high at the close of the Pennsylvanian the seas were only moderately constricted. They merely had been pushed out of the geosynclines by rising mountain chains.

WOLFCAMP TIME

The next horizon chosen for mapping is that of the greatest extension of the Permian seas during the Wolfcamp epoch. This is arbitrarily taken to be the horizon of the Coleman Junction limestone of central Texas and Cottonwood limestone of Oklahoma and Kansas. This map (Fig. 3) is somewhat similar to the preceding one except that the seas are shown to have encroached upon the sites of late Pennsylvanian mountains.

In southern Oklahoma enormous thicknesses of both continental and marine clastic sediments (Pontotoc and Stratford) were eroded

[30] E. H. Powers, "Sand Hills Area, Crane County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 119–27; Fig. 5.
C. D. Cordry and M. E. Upson, "Silurian Production, Shipley Field, Ward County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 3 (March, 1941), pp. 425–27.
West Texas Geological Society, *op. cit.*, cross section.

[31] Ronald K. DeFord and E. Russell Lloyd, *op. cit.*, Fig. 1, Central Basin platform.

[32] Emil Bose, "Vestiges of an Ancient Continent in Northeast Mexico," *Amer. Jour. Sci.*, 5, ser. 6 (1923), pp. 123–36, 194–214, 310–37.

[33] E. H. Sellards, *op. cit.*, p. 52.

from the Wichita Mountains and laid down in the Anadarko-Ardmore trough, possibly nearly filling its southeastern extension. Considerable clastic material was carried into the Texas connection of this trough south of the Red River, causing the gradation of the Coleman Junction limestone to sandstone northeastward in Archer County.[34]

From Archer County south to McCulloch County the Wolfcamp shore line has been removed by erosion, but the persistence and constant character of the Coleman Junction and other beds in this part of the section seem to indicate that the present outcrops are nearly parallel to the shore line. However, as is shown by Figure 6 there is rapid gradation basinward, first from near-shore clastics to limestones and dolomites, and then to fine sands and black shales of basin facies. This gradation seems fairly good evidence that land lay not far east of the present outcrops.

South of McCulloch County the Permian rocks are overlapped by Cretaceous, so that all of our information as to the early Permian shore line must be derived from logs of borings, which are not very numerous. To complicate matters, the lower Permian rocks in this region are composed of black shales and fine sands with some limestone beds which are sparingly fossiliferous. Detailed stratigraphic and paleontologic information on the area is not available, but the character of the rocks seems to suggest a southern source for large quantities of clastic material entering the black shale basin. These black shales and moderately fine sands are totally different from any of the near-shore sediments in the northern part of the basin. They could, of course, have been derived from the erosion of the folded Pennsylvanian sandstones and shales of the Marathon Mountains and their southeastern extension. On the other hand it is problematical whether this folded belt was of sufficient extent to furnish the vast amount of material now found in the Wolfcamp of the black shale basin.

In the Marathon region the rapid increase in Wolfcamp conglomerates toward the south,[35] indicates that highlands lay not far to the south, as shown in the map.

The presence of Hueco limestone of Wolfcamp age on the Diablo Plateau shows that this strongly positive area was submerged for a considerable part of the epoch. Probably this submergence represents a southward shifting of the western entrance to the West Texas basin. This is supported by the fact that rocks of Wolfcamp age (Abo) in the Sacramento Mountains and in wells of southern Chaves County, New

[34] E. H. Sellards, *op. cit.*, p. 141.

[35] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, p. 94.

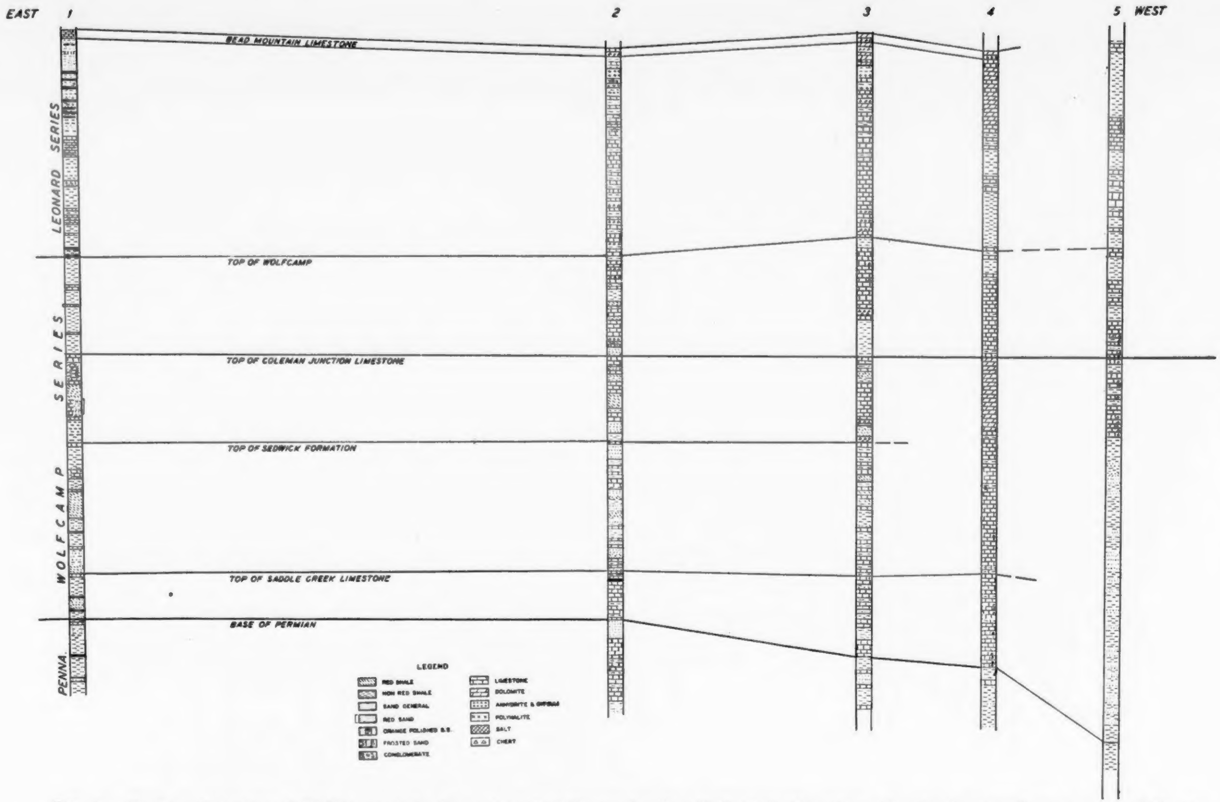


FIG. 6.—East-west section of Wolfcamp series in west-central Texas showing distinct clastic nature of series in near-shore area, gradation to limestone in shelf areas, and change to sand and dark shales in basin. Line of section shown on Figure 3.

1. Surface section, Coleman and McCulloch counties, from Plummer and Moore, *Univ. Texas Bull. 2132* (1932), pp. 165, 174, 182, 193, 196.
2. Dodson's Wilson No. 1, Sec. 1, Thomas Green Survey, Concho County. 740 to 2,370 feet.
3. Marland's Johnson No. 1A, Sec. 537, J. Heinrich Survey, Tom Green County. 1,700 to 3,350 feet.
4. Humble's Lewis and Wardlaw No. 1, Sec. 5, Blk. 17, H&TC, Tom Green County. 2,450 to 4,100 feet.
5. Kingwood's Suggs No. 1, Sec. 19, Blk. 1, H&TC, Irion County. 5,250 to 7,050 feet.

Top of Wolfcamp in surface section is that defined by M. G. Cheney, "Geology of North-Central Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 95–96.

Mexico, are of continental facies: red shales, sands, and arkoses derived from the erosion of the Pennsylvanian mountains, while marine Wolfcamp is exposed in the Jarilla Mountains a short distance southwest.[36] This shore line, marking the change between the red continental rocks of the Abo and the bedded shales and limestones of the Wolfcamp, has been traced by well records through east-central New Mexico into the western part of the Texas Panhandle where it may lie just inside the transition between the red granite wash and the Wolfcamp dolomite. Hemsell shows[37] that this same change from red clastics to Wolfcamp limestones is found from the Texas Panhandle to southwestern Kansas, so that the shore line may be sketched in here on the basis of his work.

In the middle of the Permian basin, the advance of Wolfcamp seas made long narrow islands, or possibly archipelagos, of the Amarillo mountains and the Fort Stockton mountains. The outline of the Amarillo mountains at this time can be fairly well determined from Rogatz' maps and sections.[38]

The outline of the Fort Stockton mountains in Wolfcamp time is as yet unknown, but it is becoming increasingly evident that they were emergent over a considerable area in western Crane and northern Pecos counties, where pre-Permian rocks are encountered in wells underlying Leonard beds. The relations of the Wolfcamp in this area are well shown in the West Texas Geological Society cross section. The extension of these mountains to the north under the Central Basin platform is largely hypothetical, supported only by the apparent absence of the lower Wolfcamp in two deep wells, Perkins' Cowden No. 1, in the southwestern corner of Andrews County, and Phillips' University No. 1 in the south-central part of the same county.

A portion of the Reagan uplift was emergent at this time, but much of it was soon covered by upper Wolfcamp sediments.

The Wolfcamp, then, was an epoch of widespread marine conditions, during which many of the upper Pennsylvanian mountain ranges were lowered by erosion and partially submerged by the sea. Since a marked unconformity separates the Leonard from the underlying Wolfcamp in the Glass Mountains,[39] there can be little disagreement as to the boundary in the type locality. In the area of more nearly con-

[36] C. E. Needham, personal communication.

[37] C. C. Hemsell, *op. cit.*, Fig. 3, Fig. 6.

[38] Henry Rogatz, *op. cit.* In using this author's "zones," it must be borne in mind that they are lithologic units. They coincide only very roughly with time units, and then only along the strike of the granite ridges. For a discussion as to the age relation of Rogatz' zones see Adams *et al.*, *op. cit.*, pp. 1679–81.

[39] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, p. 97.

tinuous deposition in northern Texas, Oklahoma, and Kansas there is no such well marked boundary. About this time, however, the extensive evaporite deposition began, including the Wellington salt of Kansas[40] and the Valera anhydrite of north-central Texas, which is the forerunner of the great masses of upper Permian salts and anhydrites. Therefore, it is logical to place the lower boundary of the Leonard below these formations, independently of any paleontologic evidence. This Cheney has done in his revision of the geology of north-central Texas.[41]

MIDDLE LEONARD (CHOZA) TIME

The gradual southward retreat of the marine sea continued through the upper Clear Fork of Texas, the Salt Plain of Kansas, and the upper Yeso of New Mexico. It is on this horizon that the third map (Fig. 4) is drawn.

These changed sedimentational conditions make it necessary to use a slightly different method in constructing a map. A distinction is made between the seas of different salinities as reflected by the chemical composition of their sediments. The outline of the marine sea indicates the area in which the sea water was fairly close to normal salinity. The deposits of this facies are black-to-gray sands and shales, gray limestones and brown-to-buff dolomites. Fossils are fairly common, especially in the areas of limestone deposition. It includes the normal marine and vitasaline zones of Lang.[42] The boundaries between this phase and the more concentrated saline phase are necessarily rather arbitrary, for in the well logs the stringers of dolomites gradually give way to anhydrite, and the exact point of transition is difficult to pick. Since structurally positive areas probably formed barriers which helped to restrict the circulation and increase the salinity of the sea, the outline of the dolomite-depositing sea is closely related to these structural features.

The saline sea includes within its boundaries the area in which evaporite sediments, ranging from anhydrite through halite to potash salts, were predominant. This phase includes the penesaline, saline, and supersaline zones of Lang. Potash salts, however, are uncommon in rocks older than Guadalupe.

Near the shore was another phase corresponding to Lang's brackish and fresh zones, which the writer has combined into the brackish sea. Here, the streams from the land carried large amounts of clastics, most of them red, into the seas and locally freshened them.

[40] R. C. Moore, "Stratigraphy of Kansas," *op. cit.*, p. 74.

[41] M. G. Cheney, *op. cit.*, pp. 96, 97.

[42] W. B. Lang, "The Permian Formations of the Pecos Valley of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 7 (July, 1937), p. 885, Fig. 24.

In the northern part of the region the lands apparently were low, and the deposits in the brackish sea were relatively fine-grained as in the Salt Plain and Hennessey of Oklahoma and Kansas. For a relatively short time the saline sea in Oklahoma and Kansas may have occupied a broad area.[43]

Along the south side of the Oklahoma-Kansas basin the highlands of the Wichita uplift were the sources of large amounts of clastic sediments of the Hennessey-Garber. A similar accumulation derived from the ancestral Rockies at the New Mexico end of the Wichita-Amarillo axis narrowed the saline sea in the Texas Panhandle. Even where the saline sea extended over this axis, very little salt and much anhydrite were deposited. Farther south, saline residues were deposited in large amounts during upper Yeso and Clear Fork time, for deep wells north of the latitude of Lubbock, Texas, show much salt and anhydrite at about this horizon. There seems to be a close similarity between the Texas-New Mexico section and the Kansas section.[44] These two strongly evaporitic sections are separated laterally by the highly clastic, largely continental Hennessey and Garber formations of Oklahoma. Thus, in lower Leonard time there were two basins of saline waters joined by a narrow strait over the Wichita-Amarillo axis, but closely enough related so that they reflected nearly the same diastrophic and sedimentary changes.

In the vicinity of Lubbock the salt and anhydrite of the Texas-New Mexico section grades into dolomite deposits of the marine sea. This boundary of the marine sea can be traced southwest to the north end of the Diablo Plateau, by means of well logs.

In central Texas the Choza formation of the upper Clear Fork grades rapidly toward the basin, from red shale on the outcrop through anhydrite, dolomite, and gray shale to limestone. This indicates that the present outcrop is near the original edge of the depositional basin, and narrow brackish and saline zones are accordingly shown on the map. These zones naturally become narrower and narrower as the passage to the open sea is approached and the conditions are more nearly marine.

In central Texas rocks of Permian age are overlapped by the Cretaceous, so that the shore line must be inferred largely from the amount of clastic material in deep wells farther north. On the west in the Marathon region coarse clastic sediments found in the Leonard[45]

[43] C. L. Mohr, *op. cit.*, Fig. 2, wells 12 through 19.
E. A. Obering, "Salt Deposition in the Permian Basin" (abstract), *Program 21st Ann. Meeting Amer. Assoc. Petrol. Geol.* (March, 1936), p. 12.
G. H. Norton, *op. cit.*, Fig. 2, Fig. 3.

[44] G. H. Norton, *op. cit.*

[45] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, p. 98.

indicate that the shore line must have been near and the lands behind it high.

An island seems to have occupied the area of the Van Horn uplift where recent work of King[46] has shown that the lower Leonard (Bone Spring) rocks lap out against the Wolfcamp (Hueco). However, rocks of this age appear to be present farther north on the Diablo Plateau. The upper Yeso seems to be missing, however, in a well in the northern portion of the plateau in New Mexico, probably due to the influence of the south end of the central New Mexico axis.

Thus, there was a rather broad southwest entrance to the open sea somewhat obstructed by the Van Horn island. Possibly this entrance was quite shallow, which might account for the comparatively small area occupied by the marine sea at this time.

Recently Albritton[47] has redescribed an anhydritic and dolomitic Permian formation from the Malone Mountains. The Permian age of this formation was first recognized by Baker.[48] This formation, the Briggs, carries brachiopods of Leonard age. Since, however, there is no evidence indicating to what part of the Leonard this unit belongs, it has not been possible to use these data in drawing the paleogeographic maps.

The striking characters of the geography of this period are the great restrictions of the normal sea, the great extent of the saline sea, and the beginning of the uplift which was to result in the deposition of the great masses of coarse clastics, the Duncan, San Angelo, and Glorieta.

SAN ANDRES (BLAINE) TIME

Following the deposition of these clastic beds, there was a comparatively rapid advance of the sea. In this sea were laid down the basal beds of the Blaine formation, on which Figure 5 is drawn. In the construction of this map, the writer has attempted to use, wherever possible, the horizon of the Medicine Lodge gypsum of Oklahoma and Kansas.[49] The relationships of this bed are well shown in the section by Fountain and Neely,[50] although their Haystack and Ferguson of Oklahoma apparently are the same as the Medicine Lodge of Kansas as defined by Norton.

[46] P. B. King, personal communication.

[47] C. C. Albritton, Jr., "Stratigraphy and Structure of the Malone Mountains, Texas," *Bull. Geol. Soc. America*, Vol. 49 (December, 1938), pp. 1753–57.

[48] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), p. 11.

[49] G. H. Norton, *op. cit.*, Fig. 16.

[50] *Anadarko Basin Field Trip Guidebook* (Amer. Assoc. Petrol. Geol. annual meeting, March, 1939), p. 10.

Figures 7 and 8 are cross sections which attempt to tie the West Texas San Andres to the Flower Pot, Blaine, and Dog Creek (El Reno) of Oklahoma and Kansas. The writer would like to emphasize this correlation, as it is upon such correlation that the delineation of one of the greatest floods of Permian time must rest.

Figure 7 carries the San Andres from its outcrop in south-central New Mexico across the central part of the West Texas basin to its outcrop in northern Texas. The horizon on which the map is drawn is slightly above the line on the section marked "Base of Blaine." As can be seen from this section and Figure 8, this horizon can be traced with some accuracy over most of the basin. Well No. 2 of this cross section shows the Glorieta type sands which were carried in from the south end of what remained of the ancestral Rockies throughout lower Blaine time. Since no evaporites or near-shore clastics accompany this sand with its clean, well sorted, and rounded grains, the boundary of the marine sea has been drawn some distance northwest. To the east the lower Blaine beds remain largely marine limestones and dolomites, in spite of the rapid gradation of the overlying beds into evaporites. However, near the Floyd-Cottle county line, the lower Blaine section becomes almost entirely anhydrite so that the boundary between the marine and saline seas is drawn at that point near well No. 9. Since the surface section contains large amounts of red shales as well as much evaporite, it probably lies near the old shore line.

The surface section at the east end of Figure 7 forms the south end of Fountain and Neely's cross section. This cross section has been used, together with those of Green and Mohr,[51] to locate the approximate boundaries of the sea in western Oklahoma. The boundaries thus drawn reflect clearly the positions of the Wichita-Red River uplift, the Anadarko basin, and the approach to the northeast edge of the Kansas basin.

Figure 8 is a south-north cross section designed to show the correlation between the solid dolomite San Andres section of the southern part of the West Texas basin through the anhydrite and salt sections of the Texas Panhandle to the vestigial section of the lower Blaine in the Oklahoma Panhandle. The same remarkable persistence of marine beds in the lower Blaine, which was observed in Figure 7, is seen again in this section. Here, even some limestone appears in the lower Blaine dolomite as far north as Potter County, where all the overlying beds have graded into evaporites. This basal Blaine dolomite continues

[51] Darsie A. Green, "Major Divisions of Permian in Oklahoma and Southern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12 (December, 1937), pp. 1516–22. C. L. Mohr, *op. cit.*, Fig. 2.

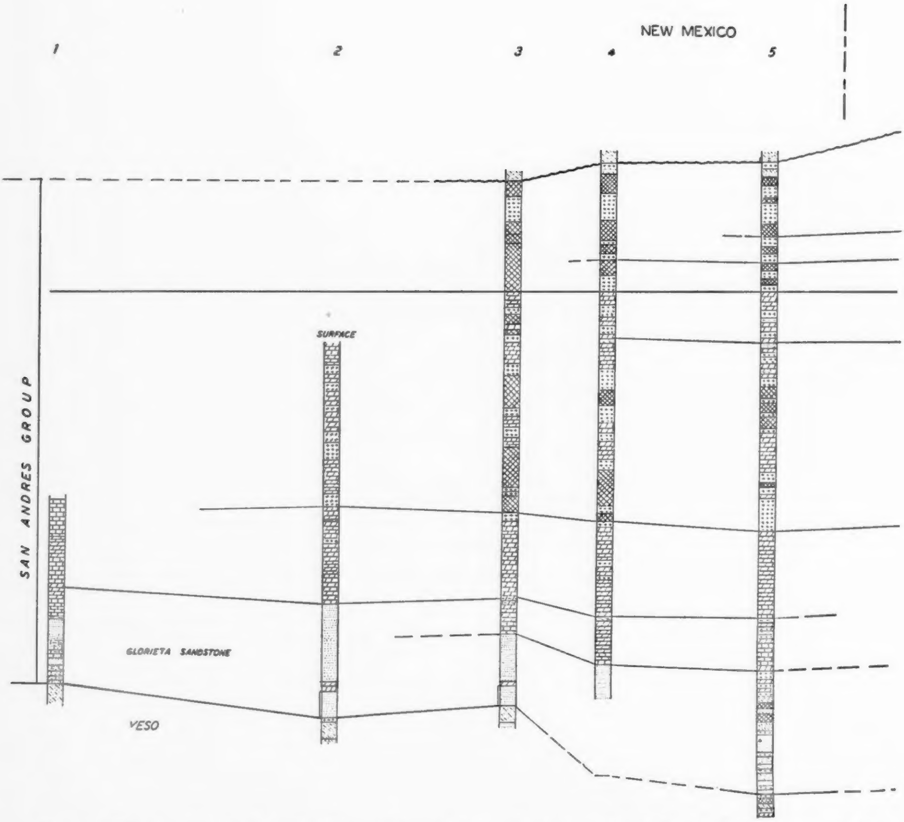
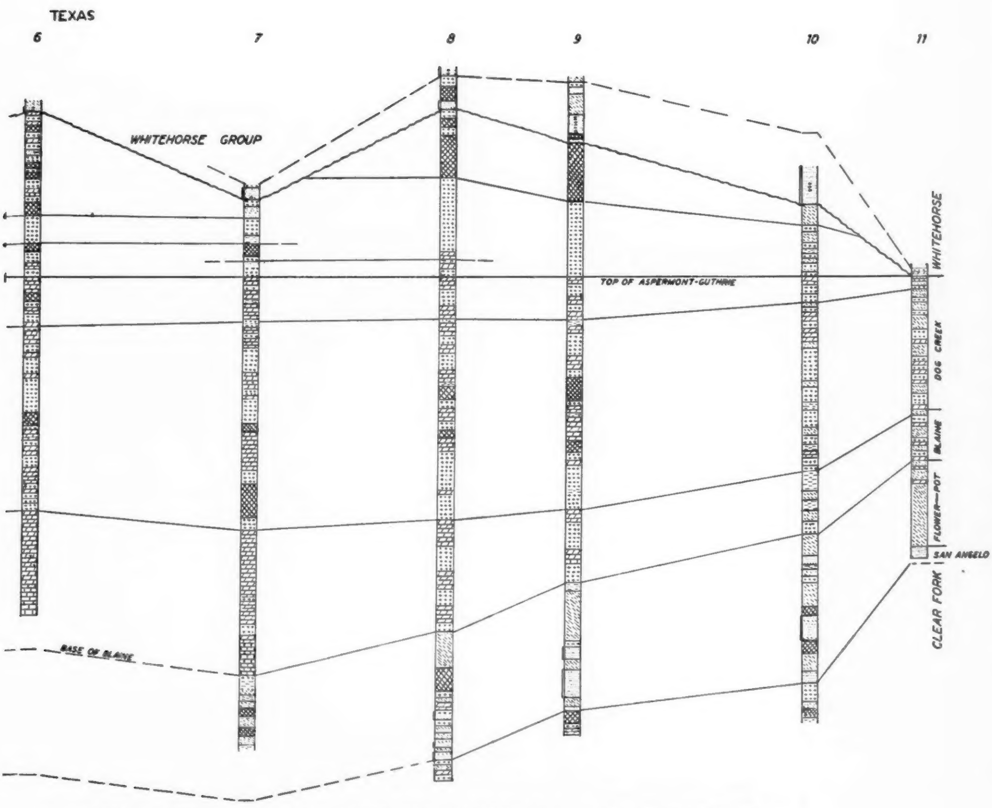


FIG. 7.—West-east section across Permian basin showing relationship of San Andres of central New Mexico to Dog Creek, Blaine, and Flower Pot-San Angelo of north-central Texas.

1. Surface section of Picacho (San Andres) limestone 3.9 miles east of Picacho, Lincoln County, New Mexico, measured by S. S. Nye, *U. S. Geol. Survey Water-Supply Paper 639* (1933).
2. Transcontinental's McWhorter No. 1, Sec. 6, T. 3 S., R. 22 E., DeBaca County, New Mexico.
3. Navajo's McAdoo No. 1, Sec. 16, T. 1 S., R. 27 E., DeBaca County, New Mexico.
4. Clovis' Sheely-Smith No. 1, Sec. 17, T. 2 S., R. 30 E., Roosevelt County, New Mexico.
5. Sloan and Smith's Lovern No. 1, Sec. 4, T. 2 S., R. 35 E., Roosevelt County, New Mexico.



6. Etz and Roberts' Enochs No. 1, League 182, Floyd Co. S. L., Bailey County, Texas.
7. Dyer's Elwood No. 1, Secs. 9 and 10, Blk. T, T. A. Thompson, Lamb County, Texas.
8. Exploration's Boone No. 1, C. H. Johnson Survey, Floyd County, Texas.
9. Exploration's Matador No. 1, Sec. 119, Blk. D-3, D&P, Floyd County, Texas.
10. Exploration's Richards No. 1, Sec. 4, D&W, Cottle County, Texas.
11. Surface section, Fountain and Neely, Foard and Childress counties, Texas. *Anadarko Basin Field Trip Guidebook* (Amer. Assoc. Petrol. Geol. annual meeting, Oklahoma City, March, 1939).

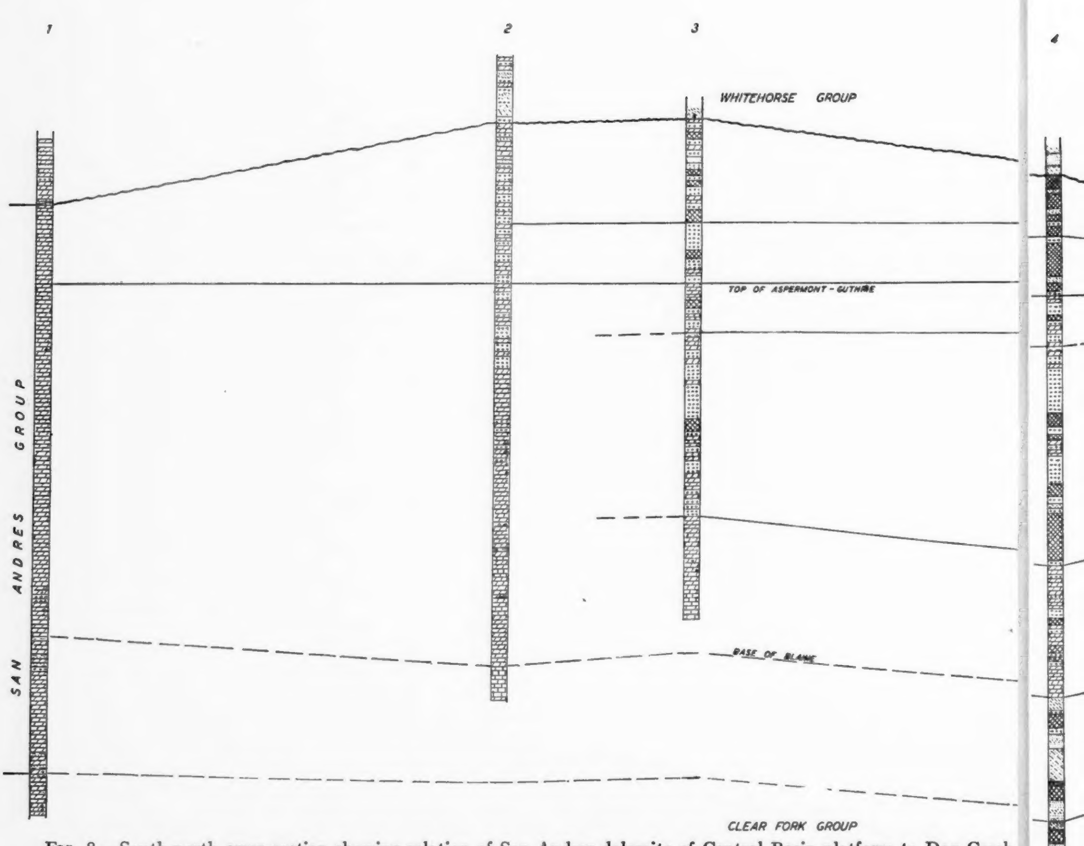
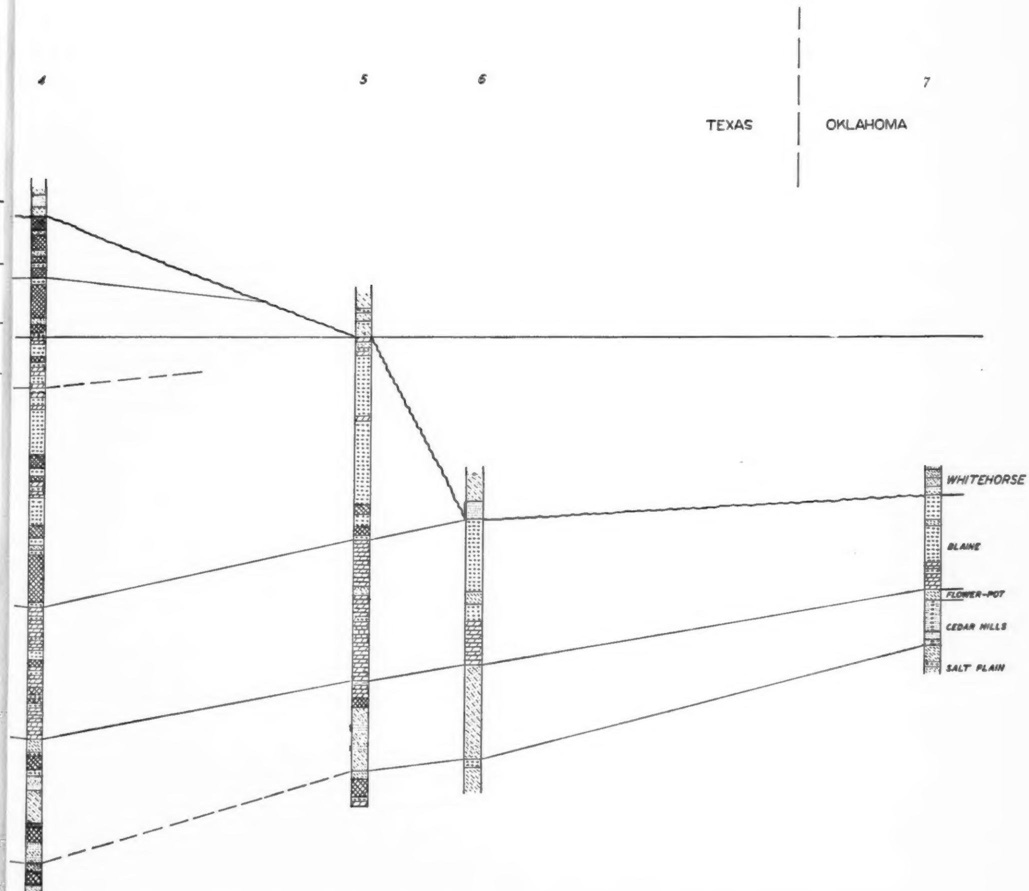


FIG. 8.—South-north cross section showing relation of San Andres dolomite of Central Basin platform to Dog Creek-Blaine of Texas and Oklahoma panhandles. Gradation northward from dolomite to anhydrite and salt is well shown as well as extreme truncation of Dog Creek and Blaine by Whitehorse group in northern part of Texas Panhandle. Section is set up on prominent dolomite bed which is approximate equivalent of Aspermont-Guthrie dolomite sequence in north-central Texas.

1. Perkins' (American Liberty) Cowden No. 1, Sec. 14, Blk. A-55, PSL, Andrews County.
2. Sloan and Zook's Fitzgerald No. 1, Sec. 22, Blk. D, J. H. Gibson, Yoakum County.
3. Etz and Robertson's Enochs No. 1, Labor 66, League 182, Floyd Co. S. L., Bailey County.

4.
5.
6.
7.
Kansa



4. Uscan's (Western Union) Farwell No. 1, Sec. 18, T. 2 N., R. 2 E., Capitol Ld., Deaf Smith County.
5. Sinclair-Prairie's Bush No. 1, Sec. 23, Blk. 6, BSF, Potter County.
6. Gulf's Kilgore No. 1, Sec. 22, Blk. PMC, EL&RR, Moore County.
7. Section in Sec. 35, T. 5 N., R. 5 E., Cimarron County, Oklahoma, from George H. Norton, "Permian Redbeds of Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 12 (December, 1939), p. 1764, Fig. 3, section A.

even as far north as section 7, which is the southernmost section in Norton's Figure 3. Norton's Figures 2 and 3 show this basal dolomite of the Blaine extending through much of western Kansas and seem to indicate a short-lived marine passage northwest into Colorado.

Norton's Figure 2 joins Fountain and Neely's section in Woodward County, Oklahoma, so that there is a closed network of cross sections supplemented by Green's and Mohr's[52] sections from which the paleogeography of Kansas, northwestern Oklahoma, and northern Texas can be (at least approximately) inferred.

In north-central New Mexico the remnants of the old highlands were apparently still being actively eroded, for wells in Guadalupe, eastern San Miguel, Harding, and Union counties show large amounts of coarse sands of Glorieta type in the lower and middle San Andres section to an even more marked degree than well No. 2 in Figure 7. Since such large amounts of clastic material suggest a considerable amount of fresh water from streams, much of this area is shown as brackish sea.

Farther west, the lower San Andres is marine dolomite and limestone in its westernmost exposures in the Socorro region and in the type area of the San Andres Mountains.[53] It possibly may connect with the Kaibab of the Grand Canyon region.

On the east and southeast side of the basin the location of the shore line of this time is indicated by numerous shallow holes, which show that the fine red and green clastics[54] reach as far west as central Sterling, Irion, and Crockett counties. This indicates that the shore line probably lay not far to the east and southeast. Apparently the saline phase of the sea did not reach as far south as this area for no evaporites intervene between the shales and the dolomites.

In attempting to trace this shore line south and west, one encounters perhaps the most pressing of all the unsolved stratigraphic problems of the Permian in the southern Mid-Continent province. This is the relationship of the San Andres to the standard marine section of trans-Pecos Texas. There is no locality where the San Andres or its equivalent beds may be traced through the edge of the Delaware basin into the standard section, either on the surface or in the subsurface. The whole group is locally fossiliferous, especially in the lower beds, but the fossil evidence is inconclusive.

This evidence has been fairly completely summarized by Lewis[55]

[52] C. L. Mohr, *op. cit.*, Fig. 2.

[53] C. E. Needham, personal communication.

[54] West Texas Geological Society, *op. cit.*, cross section.

[55] F. E. Lewis, *op. cit.*, pp. 97–102.

and by Mohr,[56] and will not be repeated here. The sum of the whole discussion concerning the age of the San Andres fossils seems to be this: ammonoids have been found in outcrops of San Andres age, on the east and west rims of the basin, which apparently are the same as those found in the Leonard on the Glass Mountains on the south rim of the basin. Fusilines have been found in the subsurface of the central part of the basin in beds which can be almost certainly correlated (see Figs. 7 and 8) with the ammonoid-bearing beds. These fusulines are not found in the Leonard of the Glass Mountains or Delaware basin but in the overlying Word formation of the Guadalupe series. Therefore, to one who is not a paleontologist, it seems that the range of either one or both of these groups of fossils must be imperfectly known, or that the correlation of the fusuline-bearing beds of the subsurface with the ammonoid beds of the surface must be in error. Since the subsurface-to-surface correlations seem to be essentially correct and have been checked by hundreds of wells, the former alternative seems the more likely.

If the ranges of the critical fossils are imperfectly known, we are forced to rely on physical evidence and well-to-well correlation to place the San Andres in the standard section. The following kinds of physical evidence lead the writer to believe that the San Andres should be placed in the Leonard series rather than in the overlying Guadalupe.

First, all over the Permian basin there is a considerable angular unconformity between the San Andres and the overlying beds. This unconformity is shown in both Figure 7 and Figure 8. In many places more than half of the San Andres is missing, apparently eroded before deposition of the lowest Whitehorse beds. This unconformity is, of course, most marked on the edges of the basin, but is present in some degree over the entire region. In some areas subsurface structure maps on top of the San Andres show graded valleys and dendritic drainage that may reflect an old erosion surface. This would indicate a major break at the close of San Andres time, and thus would provide a logical top of the Leonard series and base of the Guadalupe.

Secondly, if the San Andres is equivalent to the middle Delaware Mountain (Word), the lower Delaware Mountain hiatus must be represented by the San Angelo-Glorieta clastic beds. There seems to be little evidence for a long erosion period at this time (beginning of the San Andres) comparable to that at its close. Further, the erosion period at the end of San Andres time would, under this supposition, fall between the upper and middle Delaware, or just below the Capitan. Neither surface nor subsurface evidence supports the hypothesis

[56] C. L. Mohr, *op. cit.*, pp. 1697-1701.

that there was a period of erosion at this time comparable to that at the close of the San Andres, either in the Delaware basin or the shelf area surrounding it.

Thirdly, in the subsurface where the San Andres plunges into the Midland basin or into the San Simon syncline, it grades into very fine cherty sand, siliceous shale, and cherty limestone. This cherty, siliceous phase is characteristic of this formation and has never, so far as known, been seen in younger sands. This at least strongly suggests the sands, siliceous shales, and cherty limestones of the type Leonard.[57]

Finally, and most convincing, the deep wells in the San Simon syncline and the Midland basin have encountered 400 to 500 feet more Guadalupe section above the San Andres than have wells on the adjoining platform areas. Thus, if the Grayburg formation of the platform area is lower upper Delaware or middle Delaware in age, then this extra section in the basin must be either middle Delaware or upper lower Delaware. Then the epoch of erosion at the end of San Andres time is almost entirely accounted for, and the San Andres must underlie the Delaware Mountain formation of the basal Guadalupe and probably is Leonard.

If the San Andres is classified with the Leonard, then Figure 6 becomes a map of upper Leonard time and we are justified in using the character of the upper Leonard beds of the Marathon region in drawing the southern edge of the Permian basin at this time. Since the upper Leonard beds here are considerably more clastic than the lower beds,[58] the Blaine shore has been drawn somewhat farther north than the corresponding line of Yeso time. Since both Word and Leonard marine beds are found in the Chinati Mountains,[59] the land probably lay to the southeast.

In conclusion, the outstanding feature of the paleogeography of the lower Blaine was the great extent of the marine seas with their accompanying unconformity of sedimentation, and the lowness of the lands in the east so that only fine clastic strata were deposited relatively close to shore. The Wichita uplift and the ancestral Rockies retained considerable elevation and were the source of a considerable body of fairly coarse sediments. The lands on the southeast and south seem to have been the source of only relatively fine sands and shales.

MIDDLE GUADALUPE (GRAYBURG) TIME

Figure 9 is drawn on a horizon in the upper part of the Grayburg

[57] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, pp. 98–99.

[58] P. B. King, *op. cit.*, p. 98.

[59] J. W. Skinner, *op. cit.*, pp. 186, 187.

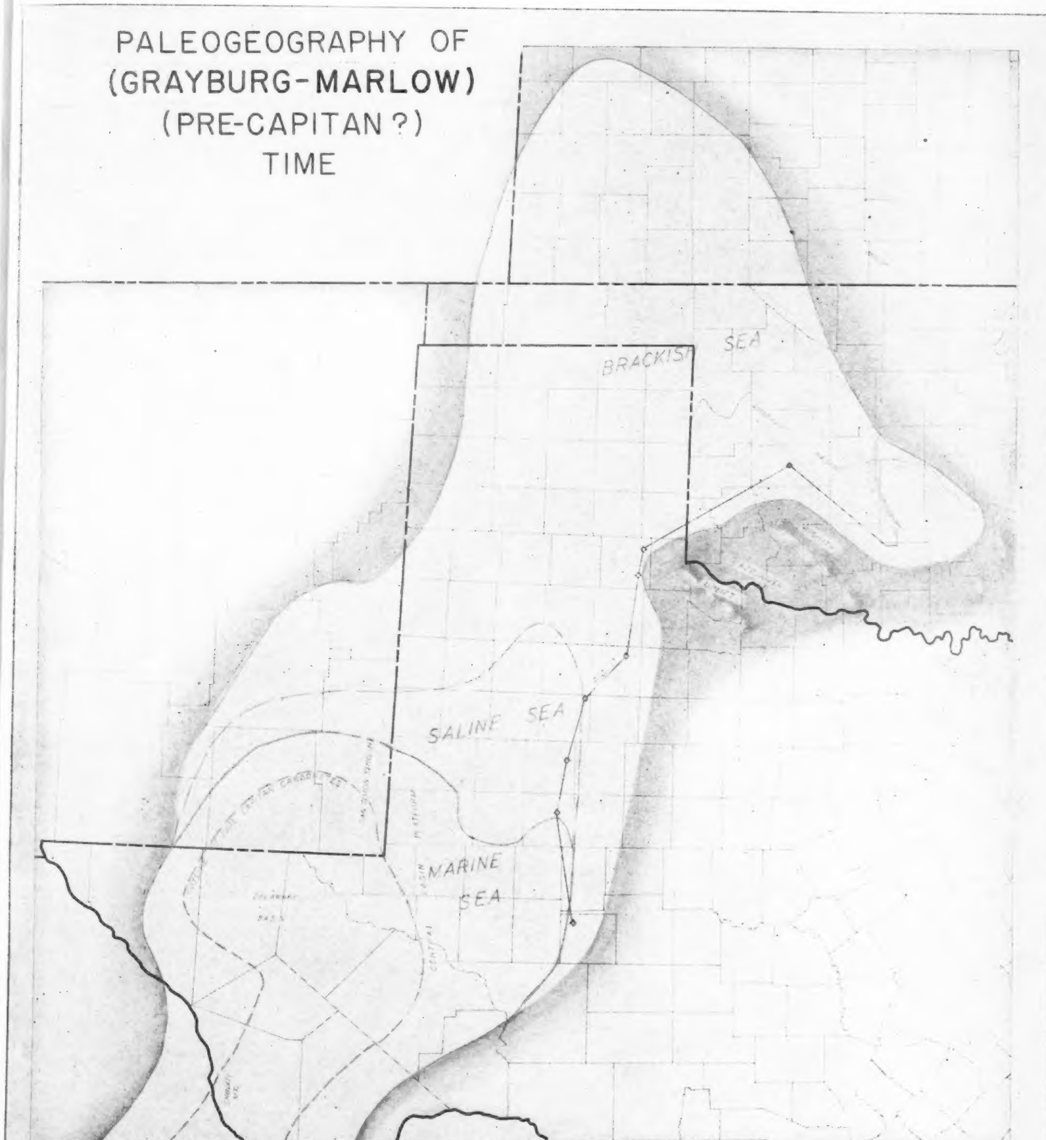


FIG. 9.—Line of section and location of wells (Fig. 10) shown along east side of basin. Notice great extension of brackish sea. Influence of Central Basin and Eastern platforms is well shown in extent of marine sea. Dashed line shows shrinkage of marine sea, clue to reef growth during Capitan time.

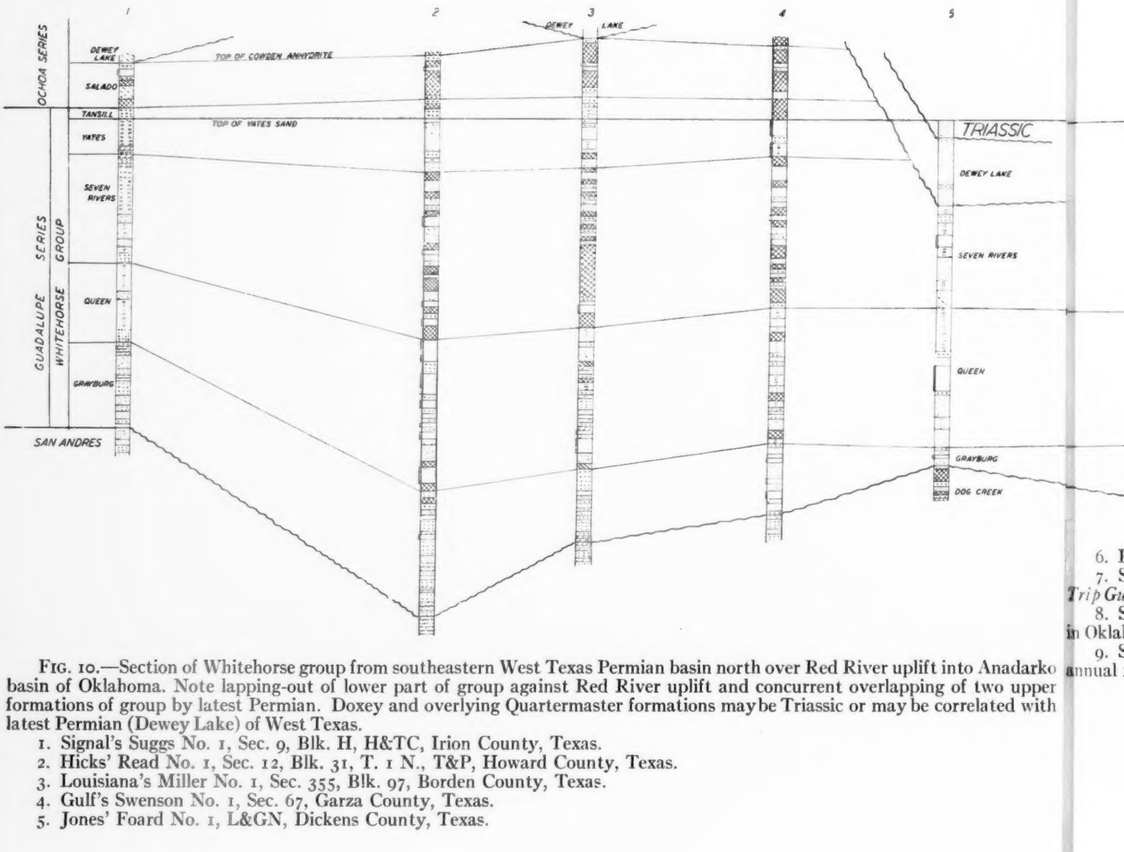
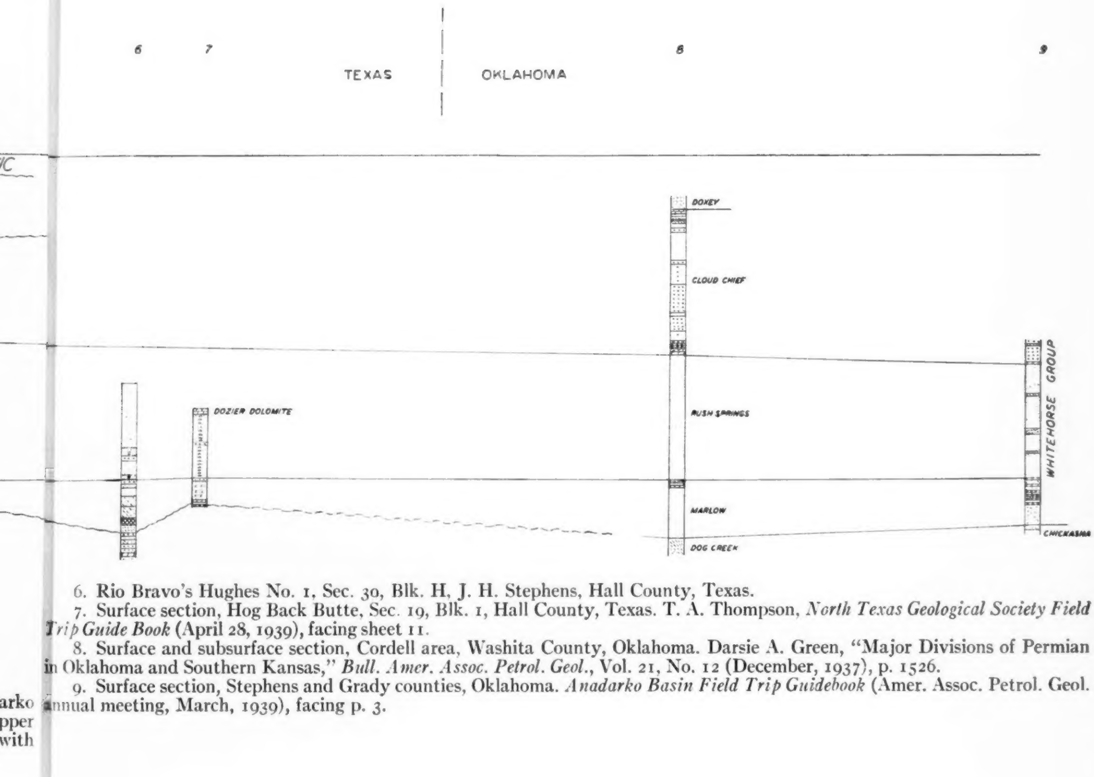


FIG. 10.—Section of Whitehorse group from southeastern West Texas Permian basin north over Red River uplift into Anadarko basin of Oklahoma. Note lapping-out of lower part of group against Red River uplift and concurrent overlapping of two upper formations of group by latest Permian. Doxey and overlying Quartermaster formations maybe Triassic or may be correlated with latest Permian (Dewey Lake) of West Texas.

1. Signal's Suggs No. 1, Sec. 9, Blk. H, H&TC, Irion County, Texas.
2. Hicks' Read No. 1, Sec. 12, Blk. 31, T. 1 N., T&P, Howard County, Texas.
3. Louisiana's Miller No. 1, Sec. 355, Blk. 97, Borden County, Texas.
4. Gulf's Swenson No. 1, Sec. 67, Garza County, Texas.
5. Jones' Foard No. 1, L&GN, Dickens County, Texas.



6. Rio Bravo's Hughes No. 1, Sec. 30, Blk. H, J. H. Stephens, Hall County, Texas.
7. Surface section, Hog Back Butte, Sec. 19, Blk. 1, Hall County, Texas. T. A. Thompson, *North Texas Geological Society Field Trip Guide Book* (April 28, 1939), facing sheet 11.
8. Surface and subsurface section, Cordell area, Washita County, Oklahoma. Darsie A. Green, "Major Divisions of Permian in Oklahoma and Southern Kansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 12 (December, 1937), p. 1526.
9. Surface section, Stephens and Grady counties, Oklahoma. *Anadarko Basin Field Trip Guidebook* (Amer. Assoc. Petrol. Geol. annual meeting, March, 1939), facing p. 3.

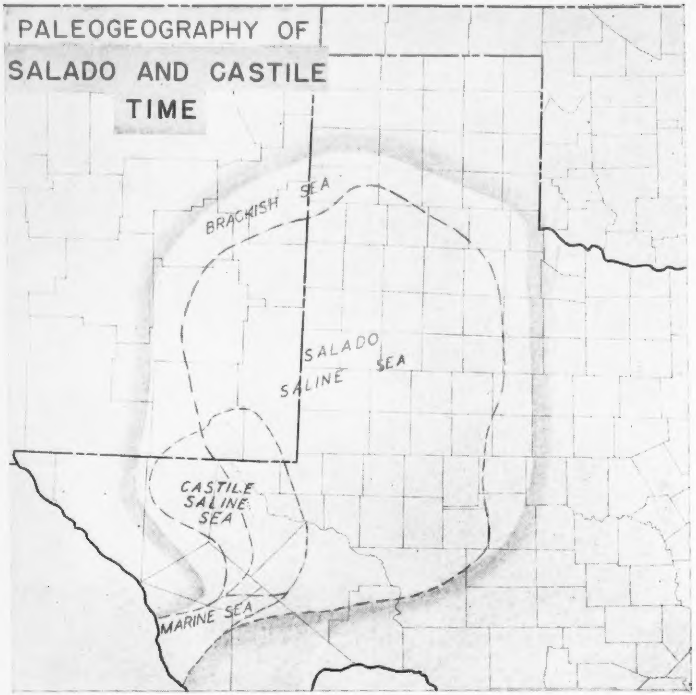


FIG. 11.—Shore line of this age is doubtful because of meager data. Notice spreading of Salado seas over most of southern part of basin excepting western Delaware basin.

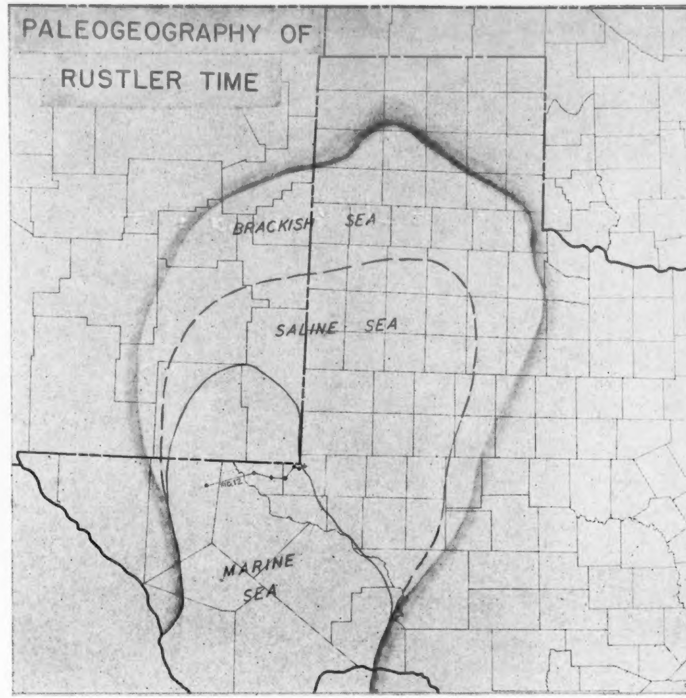


FIG. 12.—Line of cross section and location of wells (Fig. 13) shown south of southeast corner of New Mexico. Notice marine sea of Rustler time was largely confined to Delaware basin and extreme southern part of Central Basin platform.

formation, as defined by R. I. Dickey.[60] The Grayburg is a distinct unit throughout the basin back of the reef, and the upper part, on which the map is drawn, goes over the top of the Red River and Amarillo-Wichita arches to western Oklahoma where it is known as the Marlow formation. In the southern part of the West Texas basin it is sandy and shaly dolomite which grades northward into anhydrite and then into halite, after the familiar pattern of most Permian sediments. The evaporites in turn grade into the clastic sediments of the brackish near-shore sea. The formation apparently is middle Delaware in age, although its relations in the reef area along the edge of the Delaware basin are not well known.

Well-log evidence shows that the shore line of the time extended northeastward from south-central New Mexico, along the south edge of the Amarillo uplift, into Oklahoma. On the east edge of the basin the shore line seems to have been very close to the present outcrops, which are largely sands of continental origin. The seaward edge of the brackish-water clastic facies is well known from wells[61] and indicates that the brackish water facies along this side of the basin was relatively narrow. Fine red to gray shales and sands indicate a low-lying, deeply weathered land surface.

Since the Grayburg formation thins greatly and is composed largely of sand over the Red River and Amarillo-Wichita arches, it is difficult to trace it through to Oklahoma.

However, the Whitehorse section of western Oklahoma is so similar, both in the lithology and stratigraphic succession, to the upper Permian section found in Sterling, Irion, Reagan, and Tom Green counties, Texas, that there is little doubt in the writer's mind that the Marlow of Oklahoma is very closely correlative with the Grayburg of Texas. Figure 10 shows the basis on which this correlation rests.

The lithologic character of the Marlow gives some support to the correlation, since it is composed largely of finely clastic rocks with some very thin beds of dolomite and gypsum. This is the type of material that would be expected in a quiet, nearly isolated, branch of the sea, surrounded by low, deeply weathered, lands from which enough fresh water drained to keep the salinity of the water below the evaporite-depositing point, while depositing thin beds of fine clays and sands. The Marlow sea has been drawn as such an arm, occupying the Anadarko basin and joined to the main Permian basin by a shallow con-

[60] R. I. Dickey, "Geologic Section from Fisher County through Andrews County, Texas, to Eddy County, New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 45–47.

[61] West Texas Geol. Soc. cross section.

nection. In this shallow sea, sands from the Amarillo-Red River uplift were deposited.

In the brackish Anadarko sea the calcareous barrier beach known as the Verden[62] sandstone was deposited, probably closing the mouth of a bay. This is shown on the map and gives a further clue to the position of the ancient shore line. The Dozier dolomite[63] and the lithologically similar Yoakum dolomite[64] are considered to be considerably younger than the Verden and therefore are not shown on the map. Newell[65] accounts for the relic marine fossils of the Verden and similar lenses by assuming that a local reduction of the salinity of the sea behind the barrier beach afforded livable conditions for an impoverished fauna.

In northern Oklahoma and Kansas extensive use has been made of Norton's and Mohr's sections in locating the shore line of lower Whitehorse time. In the Texas Panhandle and New Mexico, numerous well logs are available. The bordering lands at this time seem to have been low and covered with shifting sand dunes, which in many places enclosed saline lagoons. Thus, the actual strand line of this time is very difficult to determine, and the line shown is only approximately correct.

The saline sea at this time was rather small, and received a relatively small quantity of sands and muds. The marine sea likewise received much clastic material, and the Grayburg is characterized by clastic material imbedded in dolomite over all of the shelf areas and the equivalent middle Delaware formation in the basin is entirely composed of fine sandstone. Since there is only a moderate increase in grain size in the sands of this age toward the edge of the basin, no very high lands seem to be indicated and the cause of the widespread deposition of sand and shale is not entirely clear.

The dotted line on this map is placed there for comparison. It indicates the extent of carbonate deposits at the close of Capitan time, considerably later than the time of the rest of the map, and shows the shrinkage of the marine seas during the last half of Guadalupe time. The southwestern entrance to the Delaware basin is largely hypo-

[62] N. W. Bass, "Verden Sandstone of Oklahoma—An Exposed Shoestring Sand of Permian Age," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 4 (April, 1939), pp. 559–81.

[63] E. H. Sellards, *Univ. of Texas Bull. 3232* (1932), p. 180. In reality, this is sandy dolomite rather than sandstone.

[64] W. C. Fritz and James Fitzgerald, Jr., "South-North Cross Section from Pecos County through Ector County, Texas, to Roosevelt County, New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), p. 25.

[65] N. D. Newell, "Invertebrate Fauna of the Late Permian Whitehorse Sandstone," *Bull. Geol. Soc. America*, Vol. 51 (1940), pp. 267–69.

thetical. It is based largely on the absence of a known Guadalupe reef in the vicinity and the presence of Capitan limestones in the Chinati Mountains.[66] It was necessary, of course, that there be an entrance into the open ocean through which normal marine circulation could be maintained in the Delaware basin. If an entrance was as narrow as shown, it must have been deep to have permitted the return of the heavier saline waters and prevented the accumulation of evaporites in the basin at this time.

LOWER OCHOA (CASTILE SALADO) TIME

The outline of the oldest sea of this epoch is shown by the dotted line of the Castile sea, in Figure 11. This sea was not much smaller in area than the Delaware basin sea of Capitan time, but the passage connecting with the open sea seems to have been either closed or much shallower, so that the dense saline waters were confined to the Delaware basin and evaporites were consequently deposited there. These sediments consisted largely of the laminated anhydrites first described by Udden.[67] Outside the Delaware basin the land seems to have been emergent, but no appreciable amount of erosion has ever been proved at this horizon. The only direct evidence of hiatus in the back-reef area is a bed of sticky maroon shale near the base of the salt on the southern part of the Central Basin platform, which may represent an old soil.

Figure 11 also shows the outline of the sea during the Salado[68] epoch immediately following the Castile. This sea extended much farther over the back-reef area than did the preceding, but did not cover so much of the western part of the Delaware basin. Its sediments are largely halite with many stringers of anhydrite and polyhalite, with some lenses of the more soluble potash salts. These differ greatly from the banded anhydrites with salt stringers of the underlying beds.

In the Glass Mountains of the Marathon region there is a massive-to-indistinctly bedded limestone about 1,000 feet thick which appears to be Permian but is younger than the Capitan.[69] Adams[70] correlated this with the Salado and possibly the overlying Rustler. The paleo-

[66] J. W. Skinner, *op. cit.*, pp. 186–87.

[67] J. A. Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. America*, Vol. 35, No. 2 (June, 1924), pp. 347–54.

[68] W. B. Lang, "Upper Permian Formation of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935), p. 267.
———, "Salado Formation of the Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 10 (October, 1939), pp. 1569–72.

[69] P. B. King, "Geology of the Marathon Region, Texas," *op. cit.*, p. 106.

[70] J. E. Adams, "Upper Permian Stratigraphy of West Texas Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 7 (July, 1935), pp. 1019, 1021.

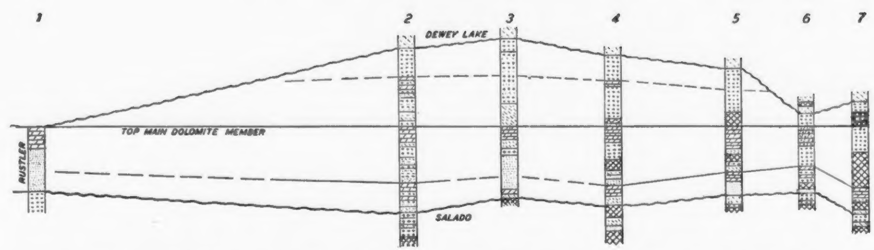


FIG. 13.—West-east cross section showing relationship of type Rustler to subsurface in Delaware basin and on Central Basin platform. Note fact that in section 2 there are three dolomite members, only the middle one of which is very persistent.

1. Type section of Rustler formation, Horseshoe Draw, Culberson County, Texas. G. B. Richardson, *Univ. Texas Bull. 23* (1904), p. 44.
2. Texas Pacific Coal and Oil's Rex No. 1, Sec. 40, Blk. 54, T. 1 N., T&P, Loving County, Texas.
3. Pinal Dome's Means No. 1, Sec. 23, Blk. C-26, PSL, Loving County, Texas. W. B. Lang, "Upper Permian Formation of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935), p. 264.
4. Skelly's Lehman No. 1, Sec. 21, Blk. 75, PSL, Winkler County, Texas.
5. Adams and Bradley's Edwards No. 1, Sec. 6, Blk. C-23, PSL, Winkler County, Texas.
6. Richardson's Sun-Jenkins No. 1, Sec. 4, Blk. 77, PSL, Winkler County, Texas.
7. York and Harper's Gunter and Munson No. 1, Sec. 7, Blk. C, GMMB&A, Winkler County, Texas.

geography seems to bear out this correlation, since the great expansion of the Salado sea naturally would be expected to bring the carbonate-depositing seas into Texas from the south where it has retreated in Castile time. As has been pointed out, well logs show the Salado section grading into anhydrite and dolomite in central Pecos County, so that it probably becomes entirely dolomite and limestone in the Glass Mountains.

The position of the strand line in Salado time is somewhat uncertain. Therefore on the map the sea is not extended very far beyond the present limits of the salt of this age, for it seems probable, from the manner of salt deposition, that such deposits never were formed very far from the present limits of the basin. The relationships of the western edge of the basin are well shown in the West Texas Geological Society cross section and are described by DeFord *et al.* in the Guidebook of the West Texas Geological Society of September 28 and 29, 1940, and also in Kroenlein's cross sections.[71]

The Salado has not been extended into the Anadarko basin, since these beds seem to be definitely overlapped by the Dewey Lake and Triassic Dockum group along the south side of the Red River uplift, and the writer has seen no convincing evidence to show that these beds come in again on the north side of this uplift. It is, of course, possible that some of the clastic beds (Quartermaster) above the Cloud Chief gypsum may represent a thin semi-continental phase of Salado deposition. This correlation would require a hiatus, representing Tansill and Yates time, between the Cloud Chief which seems to be of Seven Rivers age (see Fig. 10) and the lower Quartermaster.

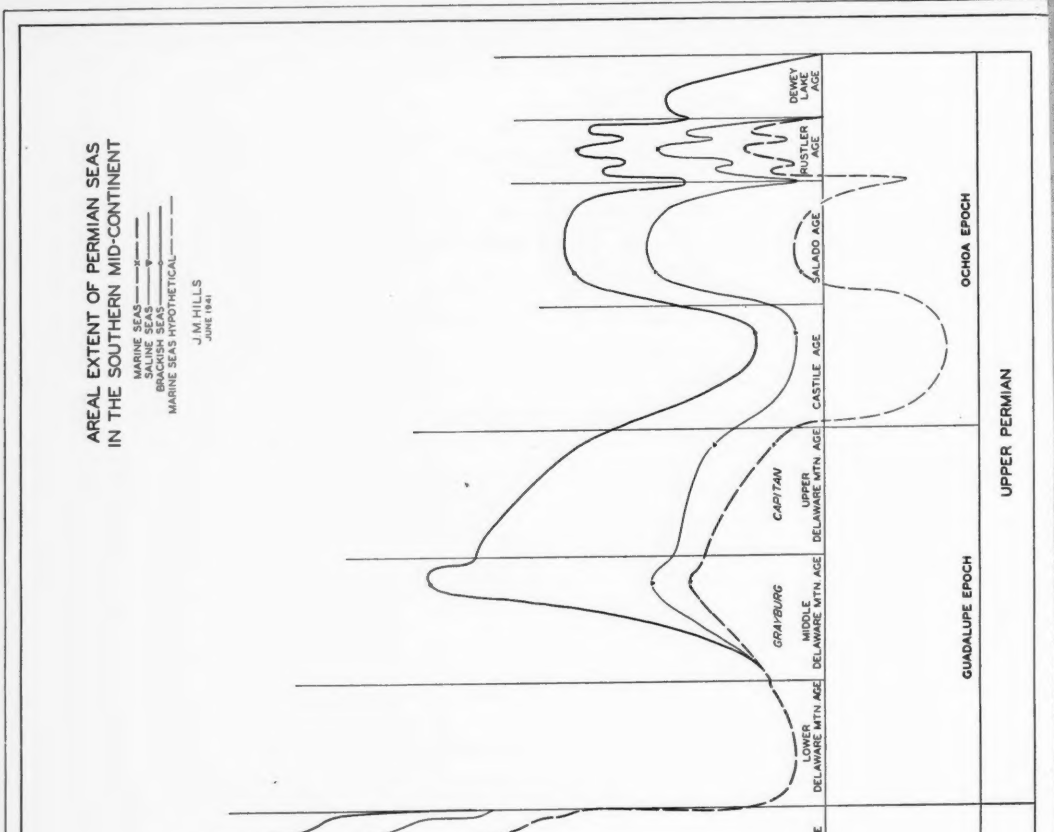
UPPER OCHOA (RUSTLER) TIME

Following Salado time a rather extensive retreat of the seas took place. The succeeding formation, the Rustler, truncates the Salado along the edges of the basin and on the prominent structural highs. The Rustler formation in the subsurface consists of some 300 to 400 feet of anhydrite, dolomite, and clastic rocks. There are two prominent dolomite members, each 10 to 40 feet thick, separated by 30 to 100 feet of anhydrite or halite, and a third lower and less prominent dolomite which occurs in the basal sands of the formation, especially in the southern Delaware basin. The cross section (Fig. 13) shows the relationship between Richardson's type section,[72] Lang's section,[73] and

[71] G. A. Kroenlein, "Salt, Potash, and Anhydrite in Castile Formation of Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), p. 1688 and Fig. 1.

[72] G. B. Richardson, "Reconnaissance in Trans-Pecos Texas, North of the Texas and Pacific Railway," *Univ. of Texas Survey* (1904), p. 44.

[73] W. B. Lang, "Upper Permian Formation of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935), p. 264.



AREAL EXTENT OF PERMIAN SEAS
IN THE SOUTHERN MID-CONTINENT
MARINE SEAS
SALINE SEAS
BRACKISH SEAS
MARINE SEAS HYPOTHETICAL
J.M. HILLS
JUNE 1941
250,000 SQ. MI.
200,000 SQ. MI.
100,000 SQ. MI.
0 SQ. MI.
LAT. 28°30'
WOLFCAMP AGE
YESO AGE
SAN ANDRES AGE
LOWER DELAWARE MTN. AGE
GRAYBURG
MIDDLE DELAWARE MTN. AGE
CAPITAN
UPPER DELAWARE MTN. AGE
CASTILE AGE
SALADO AGE
RUSTLER AGE
DEWEY LAKE AGE
WOLFCAMP EPOCH
LEONARD EPOCH
GUADALUPE EPOCH
OCHOA EPOCH
LOWER PERMIAN
UPPER PERMIAN

FIG. 14

the sections of the Rustler encountered on the Central Basin platform.

The map (Fig. 12) is drawn on the main dolomite member shown in Figure 13. As this grades into evaporites, the line between the saline and marine seas has been drawn at the point where this bed contains less than 10 feet of dolomite. In the saline area the Rustler contains much salt interbedded with anhydrite and sand, but in the structurally low places the formation contains many thick shale beds. On the east side of the basin there is a marked gradation to clastic material.[74]

On the north, the Rustler is overlapped by younger beds along the south side of the westward projection of the Red River uplift before its clastic phase is reached. This fact leaves the northern shore line of the Rustler in doubt. There seems to be no very good evidence that the Rustler sediments ever extended over the Red River uplift into Oklahoma.

Areal Extent Curves and Permian History

To illustrate the bearing the paleogeographic maps have on the history and classification of the Permian, curves (Fig. 14) have been constructed showing the areal extent of the Permian seas in the southern Mid-Continent. These emphasize some of the more important characteristics of the period, and bring out important historical facts aiding in a clear understanding of the basis for classification.

CONSTRUCTION

In constructing these curves, areas have been plotted as the ordinate and time as the abcissa. The time is, of course, only approximate and based on thickness of sediments, corrected somewhat by the estimated rate of sedimentation. Thus the upper Delaware Mountain has been assigned very much less time than the great thickness of the Capitan reef section would indicate, but considerably more time than the rather thin deposits of the upper Delaware Mountain itself would call for. The scheme follows approximately that of DeFord.[75] While crude, this method seems to best accomplish the purposes of the study.

The area, or ordinate, can be determined more exactly from the maps. Each map was measured for the area covered by each one of the seas. These were plotted, giving known points at nine different times

[74] West Texas Geological Society, *op. cit.*, cross section. Lewis stereograms.
Frank E. Lewis, "Position of San Andres Group, West Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 1 (January, 1941). See stereograms (blueprints available separate from the *Bulletin*).

[75] R. K. DeFord, "Correlation Chart," *Program of 24th Ann. Meeting Amer. Assoc. Petrcl. Geol.* (1939), p. 17.

in the Permian. The horizons at which the areas were measured are indicated by dashed lines in the correlation chart. Between these known points the extent of the seas can be more or less accurately estimated from the detailed stratigraphic data derived from well logs.

In the following paragraphs, the attempt is made to point out some of the more important features of the curves and of Permian history in this region.

WOLFCAMP SERIES

Reference to the curves shows that the Wolfcamp epoch opened with a moderate constriction of the seas, due to mountain making in the Marathon-Llanoria-Ouachita geosyncline and the uplift of the central New Mexico axis.

By the middle of the epoch, Coleman Junction time, the seas had spread to cover nearly 25 per cent more area than at the beginning. Throughout the rest of the epoch there was a gradual retreat from this peak. However, at the close there came a sharp recession of the sea, which is represented by the unconformity between the Leonard and the Wolfcamp in the Glass Mountains.

LEONARD SERIES

With the initiation of evaporite deposition in restricted seas of the early part of the Leonard epoch, it becomes necessary to use three curves for areas corresponding to the three phases of deposition distinguished on the paleogeographic maps. These curves show a relatively large area covered by all phases of the lower Leonard (Yeso) sea, but the area covered by the more or less normal marine sea was very much smaller than the area covered by the corresponding phase in the preceding Wolfcamp epoch. This fact indicates that deposition of the salt and anhydrite of the Yeso formation of New Mexico, the Valera and Clear Fork of Texas, and the Wellington and younger formations of Kansas was primarily due to restriction of the marine circulation rather than general retreat of the seas. Probably this restriction was due to local uplift in the southern part of the basin, possibly along the borders of the Delaware and Midland basins.

About the middle of the Yeso stage there was a small advance of the seas or a short period of free circulation, which resulted in the deposition of the Bull Wagon dolomite of Texas and the Stone Corral dolomite and anhydrite of Kansas. The Bull Wagon horizon represents a very persistent zone, which can be traced west from the outcrop through the subsurface into a similar zone in the Yeso of New Mexico. In the Kansas section given by Norton[76] the Stone Corral

[76] G. H. Norton, *op. cit.*, Fig. 3.

occupies a stratigraphic position similar to that of the Bull Wagon in Texas. This horizon is reflected by a distinct hump in the curve.

Toward the latter part of the Yeso stage there began a gradual uplift of the bordering lands. This resulted in some constriction of the seas and a great influx of clastics carried by streams, possibly swollen by increased rainfall. These fresh waters also enlarged the area of the brackish sea at the expense of the saline. A sharp intensification of the process brought the Yeso epoch to a close.

San Andres time opened with extensive deposition of coarse clastics. This resulted from a sharp uplift of the three major positive areas of the southern Mid-Continent. In south-central Oklahoma the Wichita ranges, and possibly the rejuvenated Ouachitas,[77] were the source of the Duncan coarse sands and conglomerates as well as the finer Chickasha sands and shales. Possibly the Cedar Hills sandstone of Kansas is the northern extension of these formations. In Texas, the Central Mineral region appeared as a positive structural element and contributed much coarse sediment to the San Angelo delta. In New Mexico erosion of the rising north-central area caused the deposition of the Glorieta sand, which extends in the subsurface as sandstone of diminishing thickness with medium coarse, rounded yellow grains as far southeast as southern Roosevelt County, New Mexico, and northwestern Terry County, Texas.

In the subsurface these clastic beds of the marginal areas can be traced into limestone and dolomite in the center of the basin. Generally, however, they retain some trace of the uplift in fine clastic material mingled with the carbonates. On the Central Basin platform these beds reach a thickness of several hundred feet.

Following this clastic deposition came the great flood of lower San Andres (Blaine) time. The curves show that the total area flooded exceeded that of Wolfcamp time, but the area covered by the marine sea, comparable in chemical character to the Wolfcamp sea, was very much less. Outside of the region covered by this paper, this epoch was one of great expansions of the sea in the Rocky Mountain region resulting in the deposition of the Kaibab and lower Phosphoria.

From this peak the San Andres sea retreated toward the south. This was accomplished in several major and many minor cycles, each consisting of a small advance of the sea during which a thin dolomite bed was deposited, followed by a slow retreat during which epigypsums[78] were formed in saline lagoons, and finally the approach of the shore line with an influx of red shales. Then followed another advance

[77] W. A. J. M. van Waterschoot van der Gracht, *op. cit.*, pp. 1014, 1028–29.

[78] *Guidebook, North Texas Geol. Sec. Field Trip, April 28–29, 1939.*

of the sea, generally not so great as the one that preceded it, and the same cycle was repeated. This sequence is well shown in the surface section by Fountain and Neely[79] and in sample logs of wells north of Gaines County, Texas.

The final retreat of the San Andres sea took place rather quickly and resulted in the sea being confined to the Delaware basin, and possibly the deeper parts of the Midland basin. Over most of the region erosion took place, which resulted in one of the most widespread and conspicuous unconformities in the Permian. Later seas were considerably more restricted, and the lithology of the Guadalupe and Ochoa series is, on the whole, different from that of the Wolfcamp and Leonard. Therefore, purely as a matter of convenience and without any intention of making a formal proposal, the writer has drawn the dividing line between the upper and lower Permian at the top of the San Andres, which is also the dividing line between the Leonard and Guadalupe series.

GUADALUPE SERIES

The Guadalupe epoch opened with the seas confined to the Delaware basin and possibly the lowest portion of the Midland basin in lower Delaware Mountain time. In middle Delaware Mountain time or possibly in late lower Delaware Mountain time the sea advanced a little in the San Simon syncline and Midland basin. During the latter part of middle Delaware Mountain time, as shown in Figure 9, the sea has spread to cover most of the Permian basin south of the Amarillo uplift and also extended into the Anadarko basin of Oklahoma.

This sea, however, was even more confined by barriers than the lower Leonard (Yeso). Reef growth, which had started on an extensive scale in San Andres time, was rapidly approaching its culmination in the Capitan. In middle Delaware Mountain time these reefs added their barriers to the already existing structural ones, so that the seas of this time had free circulation only in the Delaware basin and adjoining parts of the shelf area. Here, normal marine sediments were deposited, but in the rest of the shelf area restricted circulation caused the deposition of anhydritic dolomite, anhydrite, and halite in many partly separated basins. The sediments are characteristically clastic, even in the normal marine phase. In the quiet arm of the sea that occupied the Anadarko basin of Oklahoma, the quantities of clastic material carried into the sea by surface waters were so great that thin-bedded shales and sand (with only a few laminae of dolomite) were deposited. The extent of this brackish, clastic-depositing sea is well shown on the curve.

[79] H. C. Fountain and Joseph Neely, *op cit.*

Figure 10 shows the relationship of the Oklahoma Whitehorse to the Texas beds and general character of the Guadalupe sediments in the shelf area.

Following upper Grayburg-Marlow time, there was a sharp change in sedimentation, due presumably to the uplift of the sea floor, which resulted in a retreat of the sea to the Delaware basin. The former sea floor in the northern part of the Permian basin was covered with a complex of shifting sand dunes and short-lived saline lagoons.

Toward the southwest these saline lagoons became more extensive, until they merged into a true evaporite-depositing sea which formed the outer belt of the restricted shelf sea behind the great Capitan reef. These evaporite seas graded into dolomite-depositing seas near the reef. In the reef zone itself limestone was deposited in great masses. On the Delaware basin side of the reef in normal marine waters thin beds of fine sands with some black shales and shaly limestones were deposited, which are now known as the upper Delaware Mountain formation. As the reef grew into the basin, the carbonate-depositing zones behind it contracted in area until their outlines were those shown by the dotted line on the map (Fig. 9).

Guadalupe time was brought to a close by the cessation of growth of the Capitan reef and the sedimentary changes associated with it. Many explanations have been advanced[80] for the sudden end of reef deposition. Lloyd seems to have the fundamental explanation in a barrier across the entrance to the Delaware basin which caused the accumulation of concentrated saline waters postulated by Kroenlein. Lang seems to have the same idea in mind, since he speaks of slackening of the subsidence of the Delaware basin, permitting the choking of further reef growth by the evaporite sediments of the back-reef area. Lloyd thinks there may have been reef growth in the entrance to the basin shallowed by general uplift. This does not seem to be necessary. The only essential for the accumulation of saline waters and their sediments in a basin is an excess of evaporation over precipitation, which apparently prevailed during most of the latter part of Permian time, and an entrance to the basin sufficiently restricted so that the return flow of dense saline waters near the sea floor is smaller than the inflow of less saline waters near the surface.[81] The latter condition could come about by general uplift or, more simply, by a rather

[80] W. B. Lang, "The Permian Formations of the Pecos Valley of New Mexico and Texas," *op. cit.*, p. 892.
G. C. Kroenlein, "Salt, Potash and Anhydrite in Castile Formation of Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 11 (November, 1939), p. 1684, also discussion of this paper by E. Russell Lloyd, p. 1693.

[81] C. L. Baker, "Depositional History of the Red Beds and Saline Residues of the Texas Permian," *Bull. Univ. of Texas 2901* (1929), pp. 33-34.

small local movement along some positive axis now buried under the lavas of the Davis Mountains. Such a movement could easily make the entrance shallower so that the saline waters would be trapped in the basin and accumulate there quite rapidly, without interfering with the inflow of normal marine waters at the surface. As Kroenlein points out, when these concentrated saline waters reached the top of the reef, all of its organisms were killed and its growth was stopped. It is possible that lowering of the sea-level due to excess of evaporation over water supply was a contributing cause in the extinction of the reef.

Whatever may have been the cause, the extinction of the Capitan reef marked the close of large-scale normal marine deposition in the Permian of the Mid-Continent. The seas of the Ochoa epoch, as the curves show, were highly saline and of limited extent.

OCHOA SERIES

During the first half of the Ochoa epoch, or Castile time, the only known seas in the West Texas-New Mexico region were confined to the Delaware basin and deposited laminated anhydrite with smaller amounts of halite. But, by analogy with all the previous epochs of Permian time, there probably was a sea farther south in which circulation was less restricted and normal marine sediments were deposited. Possibly this sea lay along the line of the ancient Permian geosyncline in Coahuila, Mexico.[82] On a hypothetical basis and purely to round out the diagram, the extent of such a sea is shown by a dotted line below the base line on Figure 14.

Following Castile time with apparently little or no interruption in sedimentation,[83] came the advance of the Salado seas. During this stage the saline seas spread over most of the southern part of the West Texas-New Mexico basin, while the more normal marine seas were confined to the Marathon region and adjoining areas northeast. The basis for correlating the Tessey limestone of this area with the Salado formation of the northern part of the basin already has been discussed. The brackish sea was represented by a halo of clastic sediments around the edge of the basin, largely truncated by younger beds but still surviving in a few places.

As would be expected, where this saline sea transgressed over the irregular structures of the shelf area it was broken up into more or less isolated basins in which evaporation continued nearly to completion and often produced deposits of various potash salts. In the latter part of Salado time the Delaware basin was filled largely by

[82] R. E. King, *op. cit.*

[83] G. A. Kroenlein, *op. cit.*, p. 1688.

evaporite deposits, and only the deepest eastern portion contained saline liquor from which potash salts were deposited. Kroenlein has described the process in some detail. Associated with this breaking up of the sea into separate basins was the deposition within the evaporite section of many beds of sand and shales, both red and gray.

From these remarks it should not be inferred that the separation of the sea into many small basins caused any great irregularity in the stratigraphic succession. The beds of anhydrite and polyhalite within the salt are remarkably regular in position and can be traced over great distances, one of them, the Cowden anhydrite, being an important marker all over the basin.[84] Nevertheless, the separation into basins is shown in several ways, namely: the greater thickness of salt, the increased amounts of clastics in the basin areas, and the presence of the more soluble potash salts in some of the basins.

At the close of Salado time there was at least a moderate recession of the seas, for the overlying Rustler formation truncates the edges of the Salado formation. The Rustler represents several distinct advances of the dolomite-depositing sea. However, circulation must have been restricted, for the dolomites are anhydritic and completely lacking in fossils excepting a few poorly preserved pelecypods. Except in the extreme south, these dolomites do not extend far outside the Delaware basin, and display the familiar Permian pattern of gradation into halite and anhydrite to the north. Following the deposition of these dolomites, marine circulation was further restricted, resulting in the formation of the upper anhydrite of the Rustler.

Near the close of the Ochoa epoch an uplift took place which ended Rustler deposition. This was followed by the accumulation of the thin-bedded orange-red sand and sandy shales of the Dewey Lake. These sands, as described by Page and Adams,[85] are distinguished from the overlying Triassic beds not only by their color and texture, but also by their greater lithification, which makes them readily identifiable in well logs. They reach a thickness of 300–400 feet and represent the closing deposits of the Permian in the United States. Probably they constitute one of the youngest Paleozoic formations known.

These sediments apparently were laid down in series of quiet, landlocked lagoons left by the retreating sea, into which numerous streams washed reworked Permian sands and muds, including the distinctive large frosted grains of the Whitehorse group. At places the

[84] S. C. Giesey, and F. F. Fulk, "North Cowden Field, Ector County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 4 (April, 1941), p. 603.
G. A. Kroenlein, *op. cit.*, Figs. 2 and 3.

[85] L. R. Page and J. E. Adams, "Stratigraphy, Eastern Midland Basin, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), pp. 62–63.

surface of the Rustler anhydrite must have been exposed, for on the crest of many positive areas we find the upper portions of the Rustler removed by pre-Dewey Lake erosion, and the Dewey Lake itself contains a good deal of gypsum, probably derived from the Rustler. This unconformity is clearly shown in Figure 13. As the end of the Paleozoic era approached, the land was uplifted so much that even this semi-continental deposition ceased and erosion set in, which ended only with the opening of the Mesozoic sedimentation in the Upper Triassic.

Classification of Permian

Inspection of Figure 14 in the light of the foregoing remarks reveals much of the physical basis for the classification followed by Adams *et al.*[86] The Wolfcamp is initiated at the close of the Marathon-Ouachita orogeny by the expansion of the normal marine seas. It was closed by a constriction of these seas. Leonard time began with a restriction of marine circulation, resulting in the deposition of the evaporites of the Wellington and Valera. This epoch was characterized by the great development of evaporites in the Yeso, Clear Fork, and Salt Plain; the great flood of largely saline and brackish water in the lower San Andres; and the following retreat of the seas into the Delaware basin at the close.

The Guadalupe epoch began with the sea confined to the Delaware basin and is characterized by moderate floods and great reefs. It closed with the seas again restricted to the Delaware basin at the extinction of its greatest reef, the Capitan. The Ochoa commenced with only saline seas in the Delaware basin, had a small marine flood in the Rustler, and closed with regional uplift and the deposition of uppermost Permian sandy shales.

Thus each epoch is a natural unit bounded either by a major orogeny, a great change in the nature of sedimentation due to broad uplifts, or a major withdrawal of the seas.

General Characteristics of Permian

In looking back over this story of the close of the Paleozoic there are two characteristics of the Permian that stand out with especial clarity and serve to distinguish it from the earlier Paleozoic periods. These are (1) the cyclical nature of the sedimentation and (2) the gradual retreat of the sea.

There are a number of major cycles shown on the curve; the advance of the seas in Wolfcamp time, retreat in lower Leonard, advance

[86] J. E. Adams *et al.*, *op. cit.*

and retreat in San Andres, advance in middle Delaware Mountain, retreat in upper Delaware Mountain, advance and retreat in Salado, advance in Rustler, and retreat in Dewey Lake time. Upon these major cycles are superimposed many smaller cycles which have left their records in beds ranging in thickness from a few feet to a small fraction of an inch. It would, of course, be impracticable to show all these on the areal-extent curve. If it were possible to plot these minor cycles, the curve would be sawtoothed rather than smooth, with each tooth representing a cycle. In this abundance of minor cycles, the Permian resembles foreland sediments from the beginning of Chester time to the end of the Paleozoic.

The normal sea reached its maximum extent during the early part of the period. The remainder of the period was occupied by a gradual retreat of the marine seas broken by readvances, each one smaller than the last. Thus, near the close of the Permian, the marine sea if it existed at all on the continental mass was confined to central Mexico. In the shallow bed of the retreating sea were laid down great masses of evaporites and red clastics such as are associated with the upper Permian almost everywhere.

The whole Mid-Continent region may be likened to a gigantic spoon, with the Delaware basin forming the center of the bowl. Throughout Permian time this spoon shrank by stages. Thus, in the bowl marine sediments were deposited, while on the shallow lip and edges evaporites were formed which retreated towards the south as the spoon became smaller. Finally, even the bowl of the shrunken spoon was filled with saline residues, clastics were washed over the top, and Permian sedimentation ceased.

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STRATIGRAPHY OF EOCENE BETWEEN LAREDO AND RIO GRANDE CITY, TEXAS[1]

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ABSTRACT

A cross section of the stratigraphic succession on the American side of the Rio Grande conforms to Kane and Gierhart's formational divisions which were established for the most part from Trowbridge's original work. The Cook Mountain has been divided into three members. The subsurface top of Cook Mountain (uppermost occurrence of *Ceratobulimina eximia*) is about 500 feet below the top of the Cook Mountain as mapped at the surface.

Cycles of deposition in the Yegua and Fayette are found to be very similar. The Mier and Loma Blanca sandstones of the Yegua, and the Salineno, Roma, and Sanchez sandstones of the Fayette, have a marine facies where they cross the Rio Grande in Starr and Zapata counties. Northward these marine sandstones wedge out and the shale members become increasingly non-marine. It is suggested that each sandstone wedge and its associated shales represents a cycle of transgression and regression of the sea.

INTRODUCTION

Along the United States-Mexican border, between Laredo and Rio Grande City, Texas, there lies a most interesting area in which to make a study of the upper Mount Selman, the Cook Mountain, the Yegua, and the Fayette formations of the upper Eocene. Within a distance of 50 miles, between San Ignacio and Rio Grande City, approximately 5,000 feet of these clastic sediments are exposed and the working out of a stratigraphic classification and the correlation of the different units affords an excellent opportunity for a study in sedimentation.

The ground work for formational divisions was of course accomplished by Trowbridge,[3] but it remained for later workers to subdivide these formations into members, and to work out details of the stratigraphy. This later work was done for the most part by Kane and Gierhart[4] in their excellent paper on the Eocene of northern Mexico.

Being engaged upon a study of the area in 1935, when Kane and Gierhart's paper was published, the writer was able to tie in the contacts and boundaries worked out by them in Mexico with those across the line in the United States. It is regretted that Kane and Gierhart did not name the shale members between their Yegua and Fayette sandstones. The writer has deemed it advisable to introduce some new

[1] Presented in part at the annual meeting of the South Texas Geological Society at Brownsville, Texas, October 21, 1939. Manuscript received, September 19, 1941.

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[3] A. C. Trowbridge, "Tertiary and Quaternary Geology of the Lower Rio Grande Region, Texas," *U. S. Geol. Survey Bull. 837* (1932).

[4] W. G. Kane and G. B. Gierhart, "Areal Geology of Eocene in Northeastern Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 9 (September, 1935), pp. 1357-88.

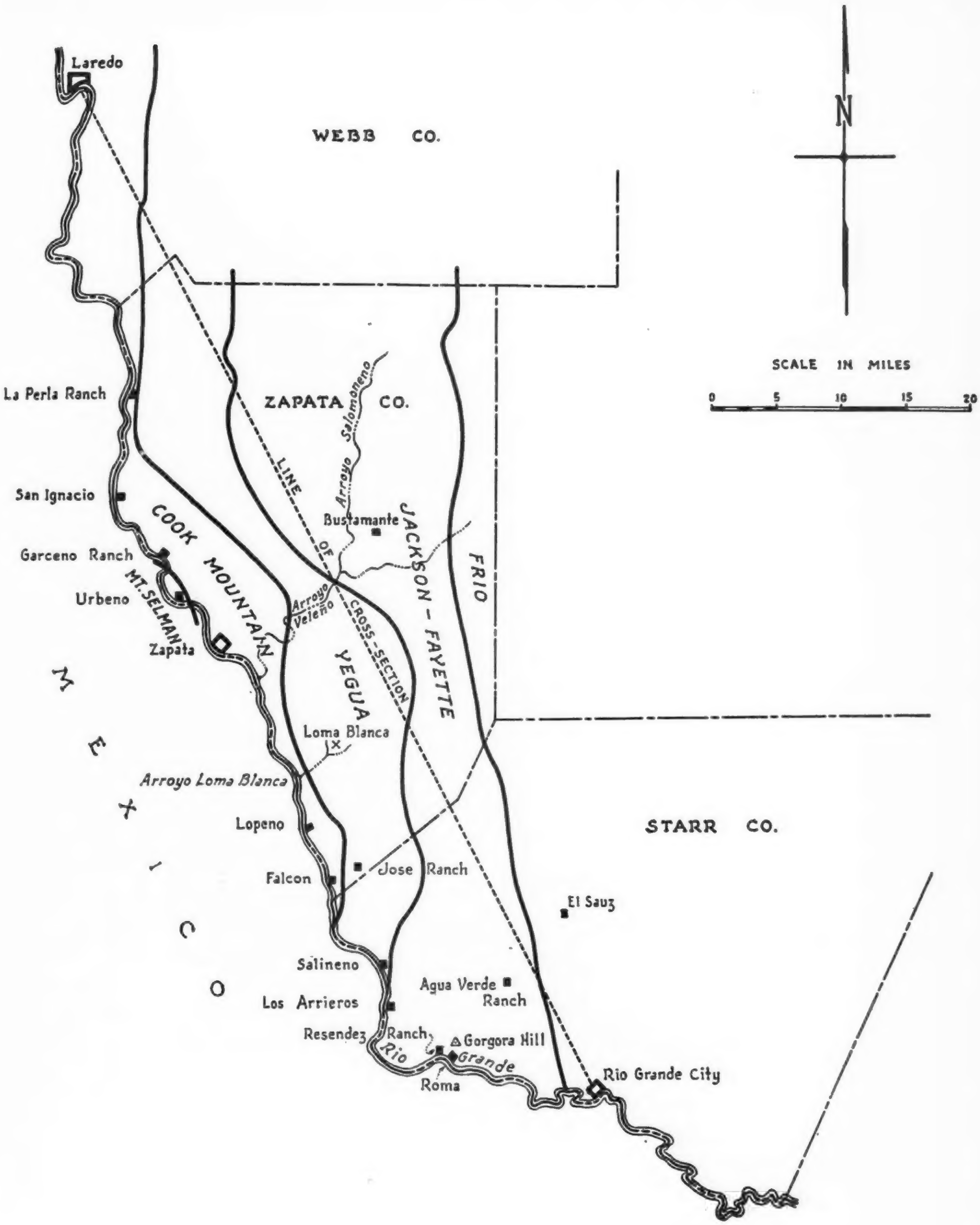

FIG. 1.—Map showing areal geology and line of cross section.

names in order that the larger mappable units in the area under discussion can be delimited.[5] The intergrading of non-marine, lagoonal and marine shales is complex; consequently it is impractical to give separate names to these different facies within a single shaly unit.

Acknowledgments

The preliminary work in the area was begun early in 1935 with the pleasant association and collaboration of F. B. Notestein. John C. Miller, C. C. Miller, and L. H. Morris of The Texas Company have given much assistance toward an attempt to solve some of the problems involved in the area. Discussions with geologists in the field, and at the annual meeting of the South Texas Geological Society, in Brownsville, October 21, 1939, where this paper was presented in part, have given valuable information and suggestions which have been incorporated. Sincere thanks are given The Texas Company for permission to publish this paper.

Areal Geology

A generalized map of the formational outcrops between Laredo and Rio Grande City is shown in Figure 1. The contacts are in rather close agreement with Trowbridge who however did not classify the different members of the formations in the detail later worked out by Kane and Gierhart. Kane and Gierhart were the first to recognize the presence of the Mount Selman formation just north of the town of Zapata, Zapata County. The writer is accepting the formational contacts of Kane and Gierhart which, as explained in their paper, substantially corroborate most of the contacts of Trowbridge.

The regional dip is eastward into the Rio Grande embayment. The rate of dip increases from 100–250 feet per mile in the Fayette up to 700 feet per mile in the Mount Selman beds.

The area is quite arid and sparsely populated with Mexicans who exist for the most part by raising goats and cattle. There are some small irrigated areas along the Rio Grande where vegetables are raised for winter markets. Ninety per cent of the terrane is covered with mesquite, black brush, and cactus. Recent river cobble, soil, and transported sands in many places obscure the underlying bed rock.

Stratigraphy

General

In working out the stratigraphy considerable advantage is obtained by beginning in the southern part of the area and following the

[5] New names introduced in text are available according to Alice S. Allen, secretary, committee on geologic names, U. S. Geol. Survey, Washington, D. C.

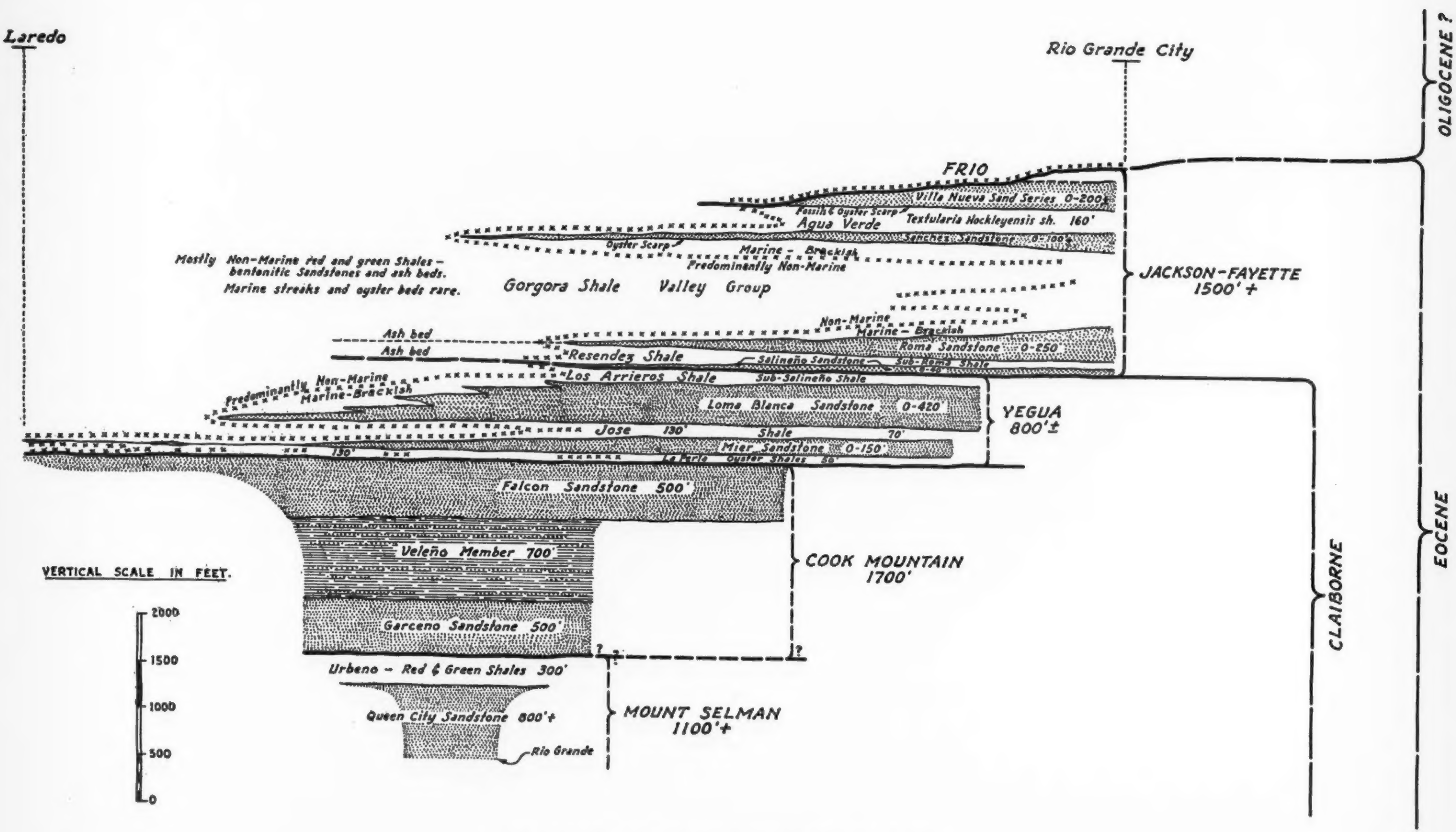

FIG. 2.—Cross section from Laredo to Rio Grande City.

recognizable members of the different formations northward. In this way, working down in the section, the marine sand wedges and the northward change in the shales can be more readily followed and the relationships of one to the other more accurately worked out.

The Corps of Engineers, U. S. Army, has made excellent topographic maps covering the entire district, scale 1 inch to 1 mile, which proved to be quite serviceable in mapping the geology of the area.

Numerous sections were measured by hand level, stepping from bed to bed where possible. Projection of dip supplemented the hand-level work in areas of poor outcrops. Lithological and paleontological data from wells drilled for oil have also been used to fill in the geologic column. Because of limitations of surface and subsurface information available in certain localities some tentative statements of thicknesses are given.

MOUNT SELMAN FORMATION

At the foot of the geologic column, on the American side of the Rio Grande, there are approximately 1,000 feet of Mount Selman beds exposed. The lower 700 feet are probably Queen City in age. These beds are overlain by 300 feet of marine and non-marine shales and sandstones that have been correlated with the Weches formation. This section is exposed just northwest of the town of Zapata as shown in Figure 1.

The 700 feet $\pm$ of beds designated as Queen City are thought correlative with beds of the same name downdip from the outcrop. The Queen City consists of alternating beds of sandstone and shale. The sandstones are medium- to fine-grained in texture and in general are gray to yellowish brown in color. A number of the sandstones are glauconitic and tend to assume a greenish color. Some beds of sandstone are fossiliferous, but fossils are rare compared with those in the marine sandstones of the Cook Mountain, Yegua, and Fayette. The shales of the Queen City appear to be non-fossiliferous and range from dark gray to greenish gray in color. A number of shale samples were collected and studied by L. H. Morris who was unable to find any fossils on the basis of a microscopic examination. The proportion of sandstone to shale is roughly in the ratio of sixty to forty.

The Queen City is overlain by about 300 feet of red and green shales with some sandstones which have been described by Kane and Gierhart as the uppermost member of the Mount Selman. These beds have been assigned by them to the approximate age of the Weches. A continuous section of these shales is clearly seen at the road crossing

in the second creek ¾ mile northwest of Urbeno, Zapata Quadrangle.[6] Also at that locality the lower contact with a thick Queen City sand bed and the upper contact with massive Cook Mountain sandstone are well exposed. The lower half of this member is characterized by red, purple, and green shales with a few beds of thin glauconitic sandstones. The upper half of this section contains more marine beds than the lower half. The upper 30 feet is a fossiliferous shale associated with marine, megascopic shells. The top of these shales or the lower part of the sandstone member above, which has been assigned to the Cook Mountain, is very close to the horizon of the first occurrence of *Textularia smithvillensis* in Humble's Dominguez well No. 1, 10 miles east of Zapata. As yet no surface samples have been found which contain *Textularia smithvillensis*, diagnostic foraminifer for the top of Mount Selman.

COOK MOUNTAIN FORMATION

The Cook Mountain formation of the Claiborne group of the Eocene is divisible into three parts in Zapata and Starr counties, Texas: a basal sandstone member 500 feet thick, a middle shale and sandstone member 700 feet thick, and an upper sandstone member 500 feet thick. Northward this formation thins so that in central Webb County this subdivision of the Claiborne group is less than half as thick as it is in Zapata County. The formation in Webb County is principally sandstone since the middle shaly member has thinned down from a thickness of 700 feet to a thickness of 150 feet. The Cook Mountain is very fossiliferous throughout and indicates deposition under continental-shelf, marine environment.

GARCENO SANDSTONE MEMBER

In the classification of the stratigraphic units of the Cook Mountain formation a thick basal sandstone member has been found which is here named the Garceno sandstone. The name is taken from the Garceno ranch house, located on an outcrop of this sandstone, 9 miles northwest of the town of Zapata (see Figure 1). This ranch house is on the American side of the Rio Grande and is situated in the lower part of the Garceno sandstone. A short distance southeast the base of the member is well exposed and is quite accessible in the creek previously referred to ¾ mile northwest of the town of Urbeno.

The Garceno sandstone is approximately 500 feet thick. With the exception of a 50-foot, dark-colored, marine shale coming in about

[6] *Zapata Quadrangle*, Corps of Engineers, U. S. Army, Tactical Map, 1930, reprinted 1931.

150 feet above the base, it is composed of glauconitic marine sandstone beds. The sandstones are highly fossiliferous and in the lower 100 feet of this member, black chert pebbles are very common. These pebbles attain a maximum of 1 inch in diameter.

Throughout this member of the Cook Mountain the peculiar marine fossil "borings," *Halymenites major* Lesquereux,[7] referred to by Stenzel[8] in a description of the Eocene beds of Leon County, Texas, make their first plentiful appearance.

VELENO MEMBER

It is herewith proposed that a middle member of the Cook Mountain, 700–800 feet thick, be named the Veleno member of the Cook Mountain, from Arroyo Veleno (misspelled Boleno on topographic map), which enters the Rio Grande 3 miles southeast of the town of Zapata, Zapata Quadrangle. The upper beds of this member are well exposed in the lower 2 miles of Arroyo Veleno, and the topmost shales of this member are in contact with the overlying Falcon sandstone in the adjoining bluffs on the east.

The Veleno member consists of alternating beds of shale and sandstone as differentiated from the practically solid sandstone members below and above. The member consists of about half sandstone and half shale beds. The sandstones are calcareous, fossiliferous, concretionary, and in many places glauconitic. The "animal boring" *Halymenites* is very common as well as *Natica dumblei* and other fossils. The shales are, in a few places, green, gray, bentonitic, and gypsiferous, but the greater part of the shale beds are found to be carbonaceous, fossiliferous, and to weather to a chocolate color. The weathered chocolate color of these carbonaceous, fossiliferous shales, is one of the outstanding characteristics of this member. The top of the Veleno has been correlated with the horizon of first *Ceratobulamina eximia* encountered in a sample from 784–814 feet in Humble's Dominguez well No. 1 previously referred to as located 10 miles due east of Zapata. The base of this member is clearly exposed on the paved Zapata-Roma highway, $\frac{1}{2}$ mile east of the town of Zapata where the basal chocolate and green gypsiferous shales of the Veleno are in contact with the top of the Garceno sandstone. For a distance of 3 miles southeast of Zapata, along the banks of the Rio Grande as well as in the broken topography to the east, the different beds of this member are well exposed. The uppermost carbonaceous shale of this member

[7] The writer has submitted a brief discussion of the occurrence of this fossil for publication in the *Journal of Paleontology.*

[8] H. B. Stenzel, "Geology of Leon County," *Univ. of Texas Bull. 3818* (1938), pp. 68–70.

in contact with the thick Falcon sandstone member above crosses Arroyo Veleno, 3 miles due east of Zapata.[9]

Northward the entire member goes back into Mexico within $2\frac{1}{2}$ miles above San Ignacio. According to Oscar E. Wagner,[10] where the Veleno re-enters the United States, north of Laredo, Webb County, it has lost more than half of the thickness found in the Zapata area.

FALCON SANDSTONE MEMBER

For the upper 500 feet, approximately, of the Cook Mountain, the name Falcon is proposed, from the town of Falcon, on the American bank of the Rio Grande, 2 miles north of the Starr-Zapata county line. The village of Falcon is situated near the base of the sandstone member which bears its name. The Falcon is not notably different from the Garceno sandstone, having the same thickness and characteristics and containing black chert conglomerates and glauconitic sandstones. There are several minor shale breaks but this member as a whole is distinguished by massive, cross-bedded, fossiliferous, marine sandstone beds, with which oyster shells, gastropods, *et cetera* are associated. The top of this sandstone member coincides with the top of the Cook Mountain of Trowbridge; however, as indicated before, the uppermost occurrence of *Ceratobulamina eximia,* which paleontologists, in subsurface work, use as an index fossil for the top of the Cook Mountain, is found at the base of this sandstone, that is, in the top of the Veleno shales.

The top of the Falcon sandstone in contact with the basal oyster shales of the Yegua may be observed in many localities; for instance, $1\frac{1}{2}$ miles north of the La Perla ranch house, on the Laredo-Zapata paved highway, San Ygnacio Quadrangle.[11] The upper contact of the Falcon with the basal oyster shales of the Yegua crops out $4\frac{1}{2}$ miles east and $2\frac{1}{2}$ miles south of Zapata, on Cinco de Mayo road, just east of the U.S.B.M. Elev. 402, Arroyo Clareno Quadrangle.[12]

YEGUA FORMATION

In Starr and Zapata counties the Yegua consists of two marine sandstone and three marginal shale members. Northward, in southern Webb County, these sand members wedge out and the entire Yegua

[9] At the intersection with creek from the north which heads at B. M. Elev. 404, on the Zapata-Hebbronville road, Zapata Quadrangle.

[10] Oscar E. Wagner, Box 476, Mattoon, Illinois, private report.

[11] *San Ygnacio Quadrangle,* Corps of Engineers, U. S. Army, Tactical Map, 1931, revised 1934.

[12] *Arroyo Clareno Quadrangle,* Corps of Engineers, U. S. Army, Tactical Map, 1929, revised 1939.

section becomes a series of red and green bentonitic shales with interbedded tuff and ash beds. In this northern area thin beds of comminuted oyster shells tie these otherwise non-marine beds to a marginal marine facies.

LA PERLA SHALE MEMBER

The basal shale member of the Yegua, which overlies the Falcon sandstone and underlies the Mier sandstone, is named La Perla from La Perla ranch house, located on the bank of the Rio Grande, north part of San Ygnacio Quadrangle. The La Perla ranch house rests on Rio Grande alluvium. However, it is 1 mile north of the ranch house that the basal La Perla shales are found exposed on the paved Laredo-Zapata highway as mentioned above. Also proceeding northeast of the La Perla ranch house, on the first 1½ miles of the side road to Youngs tank, these basal Yegua shales and the overlying Mier sandstone can readily be distinguished. Where the La Perla shales cross the Rio Grande south of Falcon, they have a thickness of 50–60 feet, but northward this shale member increases until east of Laredo it has attained a thickness of approximately 150 feet. This shaly member of the Yegua is characterized by an abundance of oyster beds and oyster shells scattered throughout a section of green and gray, sandy, bentonitic shales. Here and there may be found thin streaks of marine sandstones, few of which are more than 1 foot in thickness. From the town of Lopeno northward some non-marine layers of lignitic, or red and purple shales may be found, interbedded with the marine shales and sandstones. The La Perla as a whole, at Laredo, is mostly red and green shale and is not unlike the subaqueous, deltaic, marginal Yegua formation that overlies it there.

MIER SANDSTONE TONGUE

Throughout most of the area under discussion the La Perla shales are overlain by Kane and Gierhart's Mier sandstone, which, however, wedges out before the latitude of Laredo is reached. Locally, east of Laredo, thin, non-fossiliferous sandstone beds occupy the stratigraphic position of the Mier sandstone. The Mier sandstone is approximately 150 feet thick where it crosses into Starr County from Mexico, but northward it gradually thins and eventually disappears. The sandstones of this member of the Yegua are medium-grained, brown to gray, contain large calcareous concretions, and are fossiliferous throughout. Marine fossils such as shells of *Venericardia* and "borings" of *Halymenites* are plentifully represented. The basal part of the Mier sandstone forms the cuesta on the La Perla-Youngs tank road 1¾ miles northeast of the La Perla ranch house where the sandstone

reaches the approximate thickness of 40 feet. The Mier sandstone outlines the Lopeno gas structure, 4 miles east of the town of Lopeno, with the La Perla shales occupying the center of that uplift.

JOSÉ SHALE MEMBER

The predominantly red and green bentonitic shales above the Mier sandstone and beneath the Loma Blanca sandstone are herein named the José shale member of the Yegua from the José ranch house located $1\frac{3}{4}$ miles northeast of the village of Falcon, Falcon Quadrangle.[13] The top of this shale member is exposed in the east-west road $\frac{1}{2}$ mile due north of the José ranch house. This shale member, the underlying Mier sandstone, and the basal part of the overlying Loma Blanca sandstone are conveniently exposed on Arroyo Loma Blanca. At the prominent hill, Loma Blanca (white hill), $4\frac{1}{2}$ miles from the west line and $\frac{3}{4}$ mile from the south line of Arroyo Clareno Quadrangle, marked on the topographic map by elevation point 403, the contact of the José shales with the overlying Loma Blanca sandstone is very well exposed. The José shales cross the Rio Grande from Mexico near Rancho Lopeno, Falcon Quadrangle. Here they are approximately 70 feet thick. At this place these shales are in part marine green-gray bentonitic shales containing oyster layers; however, there is a non-marine red streak about 20 feet from the top which is a valuable datum for correlation purposes in that area. Northward the non-marine facies widens to include most of this member, with the exception of a thin layer of marine-lagoonal shales at the base and at the top. In the Arroyo Loma Blanca area palm stumps in place and palm leaves are preserved in red and purple bentonitic shales of this member. Around Loma Blanca the José shales have thickened to 130 feet, and this approximate thickness is maintained northward until the sandstone member above wedges out. From there on it is impossible to distinguish these shales from the overlying red and green bentonitic, predominantly non-marine shales of the upper Yegua.

LOMA BLANCA TONGUE

Above the José shales was deposited a thick sandstone member which contains practically no shale where it crosses the Rio Grande from Mexico. This member of the Yegua probably includes the Alamo and Alberca sandstones of Kane and Gierhart. Kane and Gierhart state[14] that the Alamo or the lower sandstone is correlated with F. C.

[13] *Falcon Quadrangle*, Corps of Engineers, U. S. Army, Tactical Map, 1927, revised 1938.

[14] *Op. cit.*, pp. 1374–75.

Owens' Loma Blanca sandstone. The writer herewith suggests that F. C. Owens' Loma Blanca sandstone member be enlarged to include all of an upper sandstone tongue of the Yegua which lithologically can not be subdivided on the American side of the Rio Grande. Locally there are several thin lenses of shale, sandy shale, and red streaks present, but since they are thin and lenticular, they can not be satisfactorily traced. East of Laredo it can be noted that this sandstone member which is 400 feet thick east of Falcon, has completely lensed out, having interfingered with a predominantly non-marine section of red and green bentonitic shales. As mentioned by Kane and Gierhart, this sandstone is definitely fossiliferous. To the writer it appears to be indistinguishable on lithologic grounds from the marine sandstones above or below. Large *Venericardia* shells, as well as many other types of marine shells, are present. Oyster shells and *Halymenites* are probably the most abundantly preserved fossils. As previously mentioned, the basal beds of this member are excellently exposed on Loma Blanca (white hill), Arroyo Clareno Quadrangle.

LOS ARRIEROS SHALE MEMBER

For the uppermost member of the Yegua, which is predominantly a shaly formation, the name Los Arrieros is suggested, from the village of Los Arrieros, located on the bank of the Rio Grande at the north line of the Roma Quadrangle.[15] At this locality these shales would normally crop out if they were not covered with Rio Grande silts. This member consists of gray-green bentonitic, locally sandy shale, containing many marine microfossils such as Foraminifera and Ostracoda.

Eponides yeguaensis has been identified in these shales by Kane and Gierhart. Intercalated with the shales are a number of 1-foot oyster beds. This member is approximately 110 feet thick in the Roma area and persists with that thickness northward until the enclosing sandstones lens out and the shales begin to take on non-marine characteristics. The member then becomes indistinguishable from the marginal and non-marine red and green bentonite shales of the Yegua-Jackson. A convenient locality to see these shales is on the Laredo-Roma paved highway 1.7 miles north of the point where the Salineno road turns west from the paved highway, Falcon Quadrangle. Here, at the bridge, the upper shales of the Los Arrieros are in contact with the base of the Salineno sandstone.

FAYETTE FORMATION[16]

The Fayette-Jackson, highest Eocene formation in the area, is

[15] *Roma Quadrangle*, Corps of Engineers, U. S. Army, Tactical Map, 1927, revised 1938.

[16] The writer is following the classification of Kane and Gierhart in which the names

about 1,500 feet thick in Starr County. It contains 3 prominent marine sandstone tongues separated by shaly beds of a marginal to non-marine facies. A fourth upper sandstone member, the Villa Nueva, is thought to be overlapped by the Frio (Oligocene ?) before it has a chance to normally wedge out at the surface. Shales containing *Textularia hockleyensis* are found between the Sanchez and the Villa Nueva sandstones.

SALINENO SANDSTONE TONGUE

The Salineno basal sandstone member of the Fayette has been named by Kane and Gierhart from the town of Salineno on the east bank of the Rio Grande, south part of Falcon Quadrangle, in Starr County. As this sandstone enters Starr County from Mexico it is about 40 feet thick and is recognizable for some distance north; however, as it is traced northward, like the Loma Blanca sandstone below, it gradually becomes extinct in a section of red and green bentonitic shales. As already suggested, the base of the Salineno is the base of the Fayette according to Kane and Gierhart whose conclusions are based on micropaleontological evidence. The Salineno is a highly fossiliferous marine sandstone containing oysters and other shells. It is chiefly distinguished in the Roma area by an abundance of calcareous sandy concretions which are quite fossiliferous. The "borings" of *Halymenites* are very plentiful throughout.

The approximate equivalent of this sandstone with a non-marine facies is found in the prominent west-facing cuesta on the Zapata-Hebbronville road, 1¼ miles northeast of Caliche Ranch, NW. ¼ of Arroyo Clareno Quadrangle. Here there is found a 5-foot ash bed, resistant enough that it can be traced for a number of miles northward and is a valuable reference datum for locating the Yegua-Fayette contact.

RESENDEZ SHALE MEMBER

Above the Salineno sandstone there was laid down a series of shaly beds with local developments of argillaceous sandstone and oyster streaks. It is here proposed to call this member the Resendez member of the Fayette from the Resendez ranch house, 1 mile northwest of Roma, Roma Quadrangle. In the Roma area, the shales are characterized by a very abundant assemblage of Foraminifera and Ostracoda as well as megascopic shells. The top of these shales in contact with the base of the Roma sandstone may be observed approximately 1 mile north of Roma, on the first road west, and 0.2 mile west of the

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Fayette and Jackson are used synonymously. It is understood, however, that the Fayette has been restricted so that some of the beds of the lower Jackson are not now included in the Fayette formation.

paved Laredo-Roma highway. Here in Arroyo De Los Negros and in tributary gullies are outcrops where the different beds of the Resendez member of the Fayette may be studied. Oyster beds are well developed, and the very robust *Ostrea georgiana* is present, which attains 12 inches in length. This Resendez shale member is about 80 feet thick throughout the Roma area but again like the José and Los Arrieros it apparently grades northward into non-marine bentonitic red and green shale.

ROMA SANDSTONE TONGUE

Above the Resendez shale the Roma sandstone was laid down. Exposures of typical Roma sandstone are found in the town of Roma, Starr County. This sandstone member of the Fayette at Roma is 250–300 feet thick. This member is composed almost entirely of massive and cross-bedded medium- to fine-grained sandstones which are definitely fossiliferous. It contains large oysters, *Venericardia*, and other shells. *Halymenites* is very common. Large calcareous sand concretions are rather plentiful throughout this member. Toward the north this sandstone thins and wedges completely out before it reaches Laredo. The top of the Roma sandstone and basal part of the shale member above may be observed just below the top of Gorgora Hill, triangulation station 1 mile northeast of Roma.

GORGORA SHALE MEMBER

Above the Roma sandstone is a thick, predominantly shaly, group of beds which makes a conspicuous north-south valley across Starr County and the south half of Zapata County. This shale area is bounded on the west by the east-facing dip slope of the more resistant Roma sandstone, and on the east by the west-facing cuesta made by the Sanchez sandstone. The Gorgora shale member takes its name from Gorgora Hill, located 1 mile northeast of Roma, Roma Quadrangle, where the base of the member is exposed in contact with the Roma sandstone below. In southern Starr County electrical logs show this member to be about 500 feet thick, whereas in Zapata County, on the north, it increases to a total thickness of 900 feet, for the most part at the expense of the Roma sandstone.

Through the southern part of the area, where the Roma sandstone is developed, the basal 30 feet of the Gorgora are marine or lagoonal gray shales locally carrying Foraminifera, opalized *Turritella*, and other shells. There are also some lignite beds in close association with these lower lagoonal-marine beds. North of the point where the Roma sandstone dies out these shales are indistinguishable from the Yegua and upper Fayette shales.

The thick middle part of the Gorgora member is made up of blue and green and red bentonitic shales, thin sandstones, and oyster beds as a rule less than 1 foot thick. Some of the thin sandstones are associated with marine shales which contain smooth Ostracoda, Foraminifera, and fragments of larger shells. The section in Starr County seems to have more oyster beds present and appears to be more intimately associated with local marine-lagoonal conditions than in Zapata County on the north. There thin, tuffaceous, bench-making sandstones carrying fossil wood are interbedded with red and green bentonitic shales. Northward the oyster streaks become scarce and practically the entire section has a non-marine aspect.

The upper 30 feet of this member is persistently a marine or brackish-water shale deposit which extends as far north as central Zapata County. From there on north these beds are lost because of the dying-out of the Sanchez sandstone immediately above. With the consequent lack of relief a blanket of transported soils effectively conceals the outcrop. These marine shales are green-gray, bentonitic, and contain smooth and ornamented Ostracoda, Foraminifera, and fragments of oyster and other types of large shells. As suggested already there are locally several well developed oyster beds in the topmost shales of the Gorgora member. The Gorgora-Sanchez contact is well exposed 1 mile southwest of Agua Dulce Ranch on the Roma-Hebbronville road, El Sauz Quadrangle.[17]

SANCHEZ SANDSTONE TONGUE

The Gorgora shales are overlain in Starr County by approximately 100 feet of marine sandstone beds. These beds have been given the name Sanchez by Kane and Gierhart.[18] North of Starr County this sandstone member gradually decreases in thickness and finally dies out before it gets half way across Zapata County. This is a marine sandstone formation containing *Corbula*, *Venericardia*, gastropods and other shells as well as the marine sandstone indicator *Halymenites*.

AGUA VERDE SHALE MEMBER

For the marine shales overlying the Sanchez sandstone the name Agua Verde is proposed from the Agua Verde ranch house which is shown on the north line of Escobares Quadrangle. In the first creek that crosses the north-south road, 1 mile due south of this ranch house, the top of the Sanchez sandstone is exposed. A short distance east, in tributary gullies, the basal marine Agua Verde shales containing *Textularia hockleyensis* and other Foraminifera may be found.

[17] *El Sauz Quadrangle*, Corps of Engineers, U. S. Army Tactical Map, 1938.

[18] *Op. cit.* p. 1387.

The Agua Verde shales are 150 feet thick, mostly gray-green, bentonitic shales, but contain some red non-marine beds in the upper part. In southern Zapata County the shales appear to be overlapped by the Frio, or may in part grade into non-marine shales that resemble the Frio. The area in which the Agua Verde shale crops out is limited and the beds are poorly exposed because of the heavy overburden. This shale is described by Kane and Gierhart as: "Yellow weathering gray clay with much gypsum and volcanic ash"[19] 217 feet thick.

VILLA NUEVA SANDSTONE MEMBER

Above the Agua Verde shales lies the Villa Nueva sandstone of Kane and Gierhart.[20] This member is represented at the surface in Starr County over a rather limited area northwest of Rio Grande City. There are few exposures of this member but it is probably more than 100 feet in thickness in Starr County, judged by the width of the outcrop. The base of the member may be seen in contact with the Agua Verde shales about 500 feet north of the Alta Vista ranch house, Escobares Quadrangle, Starr County. The sandstones are fossiliferous and along with marine shells contain *Halymenites* "borings." In most places a very fossiliferous bed—almost a *Turritella* coquina—marks the base of this member as pointed out by Kane and Gierhart.[21]

As traced northward this well developed sandstone appears to be overlapped by the Frio before it reaches the south line of Zapata County.

UPPERMOST JACKSON

In the Rio Grande City area of Starr County are green-gray bentonitic shales containing oyster fragments which are underlain by the Villa Nueva sandstone and overlain unconformably by the Frio red beds of Oligocene (?) age. These are the youngest beds of Fayette (?) age that are exposed in the area. These beds have not been named.

DEPOSITIONAL HISTORY

The area under discussion presents one of the best places in Texas to study the updip and downdip facies of sedimentation of the Cook Mountain, Yegua, and Fayette, in that the beds are exposed at a considerable angle to the strike of the old Eocene shore lines. Updip and downdip changes can be observed, whereas in most areas northeast in Texas, the outcrops are more or less parallel to the strike of the strand line of that ancient Gulf of Mexico. As a consequence exact

[19] *Op. cit.*, p. 1387.

[20] *Ibid.*

[21] *Ibid.*

information is not available regarding equivalents a short distance downdip, under cover. Even with the advantage of fair exposures that are oblique to the old strand lines, the depositional history of the area can be only partly grasped. It is probably more complicated than the following statements imply.

The Cook Mountain, Yegua, and Fayette beds of the Rio Grande embayment area seem to have been deposited under similar environments associated with transgressions and regressions of the Eocene sea. During this time the rate of deposition and regional gulfward sinking seem to have been in balance.

The normal cycle of advance and retreat as observed in the surface beds begins with muddy deposits in front or shoreward from contemporaneous sandy deposits. These two types of deposits could have been laid down in lagoonal and offshore-bar areas, or in bands of mud and sand similar to those described by Shepard,[22] occurring off the coast of Brazil north of the mouth of the Amazon River. Here wide, muddy continental-shelf deposits separate the strand line from offshore, sandy deposits under conditions of sedimentation which are imperfectly understood.

The more plausible explanation to the writer is the lagoon and offshore-bar theory. The lagoonal areas were shallow and of an unknown width. The sand bodies probably migrated slowly which is indicated by the presence of considerable thicknesses of muddy lagoonal deposits below and above. The "sand bars" were evidently disconnected and may at times have been wholly subaqueous since abundant marine life existed in the muddy deposits shoreward from the line of sand deposition.

Of course, seaward, shaly and, to some extent, sandy continental shelf deposits were being laid down contemporaneously with the sands and lagoonal shales.

Toward the land, deltaic, estuarine, non-marine deposits of bentonitic, red and green shales, lignites, and ashy sandstones were being deposited ahead of the marine-lagoonal muds and sands. That the terrigenous deposits accumulated almost as rapidly as the marine equivalents is indicated by the fact that there is no marked change in thickness as beds grade from predominantly non-marine to predominantly marine in character. There is a zone of intergrading of marine, lagoonal, and non-marine sediments where the history can not be accurately deciphered. Some of the beds classified as marine may be non-marine and vice versa. In fact it is possible that some of the

[22] Francis P. Shepard, "Continental Shelf Sediments," *Recent Marine Sediments* (Amer. Assoc. Petrol. Geol. 1939), p. 225.

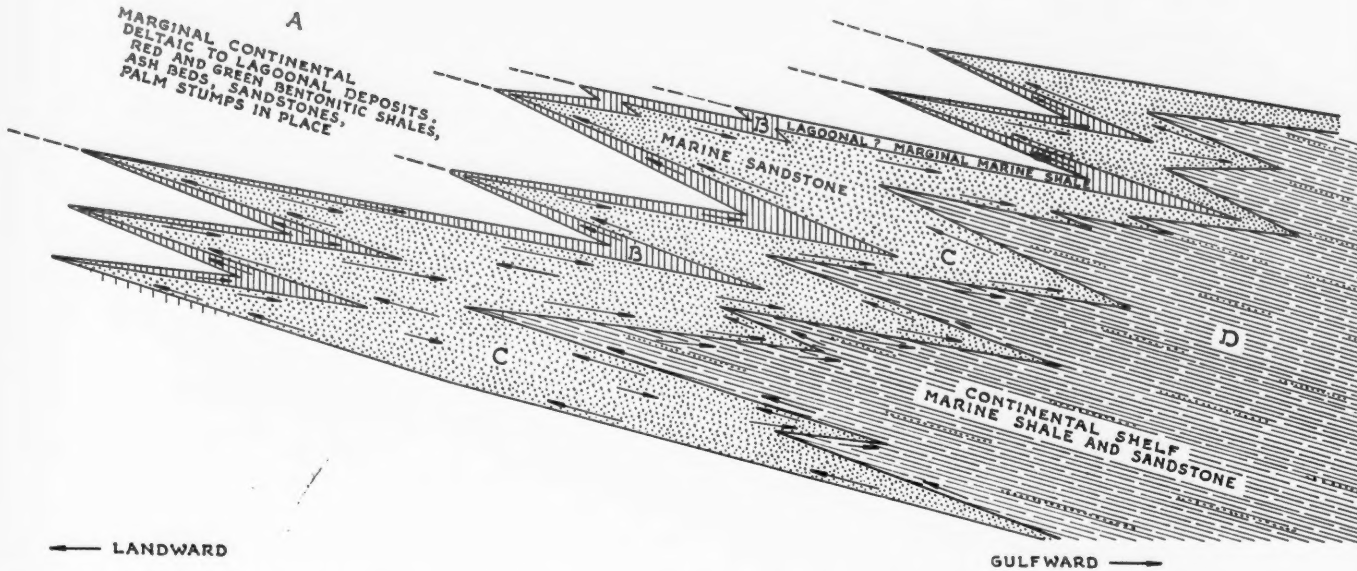

FIG. 3.—Idealistic cross section showing sediments associated with transgressions and regressions of the sea in Starr and Zapata counties, Texas. *C* and *D* show facies of exposed Cook Mountain beds. *A*, *B*, and *C* represent facies of Yegua and Fayette. Arrows indicate direction sea was migrating when beds were deposited.

red shales which are lacking in marine fossils may have been nearshore marine deposits where the water was too fresh for marine organisms, with the consequence that original lateritic red colors were preserved. It would seem that a very flat coastal area was present so that a slight raising or lowering of sea-level exposed or inundated a vast area. Evidence of this is found in the presence of thin streaks of comminuted oyster shells extending for considerable distances northward or landward in beds which otherwise appear continental.

The sea advanced, let us say, on previously deposited, rather shaly, non-marine sediments, *A*, Figure 3. They were covered by the lagoonal shales, *B*, Figure 3. No marked line of unconformity is apparent as the non-marine shales below and lagoonal shales above grade from one to the other in a zig-zag relationship. With the continued advance of the sea marine sandstone, *C*, Figure 3, was deposited above the shales with a slight wavy contact, indicating minor erosion locally. In a widespread advance the continental shelf deposits, *D*, Figure 3, might be found to overlie the marine sandstone body *C*.

When advance of the sea was halted, there was probably erosion and re-deposition of the farthest landward outposts of lagoonal shales and marine sands.

With the sea in retreat the upper sands of the marine sand wedge were laid down and as retreat was continued the lagoonal or shaly band of deposits followed the gulfward movement of the sand bar. This is suggested by the fact that shales carrying a marine or brackish fauna everywhere overlie these updip, landward sand wedges. In the continued retreat of the sea, non-marine, deltaic, paludal, at least beds with a more intimate association with continental environment, ash beds, lignites, red and green bentonitic shales lacking marine shells, are found to overlie the shales of marine lagoonal type. Thus a cycle is completed which was repeated time and again in the Eocene seas of southwest Texas.

An attempt to reconstruct the depositional history as read in the surface deposits of the Cook Mountain, Yegua, and Fayette formations of the Eocene of Starr and Zapata counties, Texas, is as follows.

The upper Urbeno shales represent the muddy deposits in advance of the Garceno sandstones, which came in after the sea had retreated in middle Urbeno time. The Garceno is probably too thick (500 feet) in this area to have been a single advancing sand body. Advance and several minor retreats of the sea must account for its present thickness in Zapata County. However, the Garceno is thought to have been primarily an advancing sand body. As the Garceno continued to advance landward this brought in the lower Veleno marine continental-

shelf deposits, which, due to their thickness, must also represent several pulsations of retreat and advance of the sea. In the next major withdrawal of the sea the upper Veleno shales and the Falcon sandstones were laid down. The thickness of the Falcon is so great that it undoubtedly is the result of several interruptions of a major withdrawal of the sea which can be visualized in the ideal cross section, Figure 3.

In the withdrawal of the Falcon sea the basal shales of the La Perla are the shoreward product of muddy deposition back of the retreating Falcon sand body. This was followed by non-marine beds which are found locally interfingering in the middle part of the La Perla shales in northern Zapata and southern Webb counties. Then in the advance in which the basal Mier sandstone beds were deposited the upper La Perla shales at the base of this sandstone, constituted muddy deposits in front of that advancing sand body. The advance and subsequent retreat depicted by the updip Mier sand wedge was followed by deposition of the José shales.

The basal José shales were deposited shoreward from the retreating Mier sand body. As retreat was continued non-marine red and gray shales and ash beds of the Middle José were laid down. When the gulf returned in upper José time, it provided the environment for marine-lagoonal-type shales which were covered later by the advancing Loma Blanca sand body. The José shales show excellent development of non-marine red beds wedging gulfward between muddy marine or brackish deposits of retreat at the base, which followed the withdrawal of the Mier sand body and muddy marine-brackish deposits of advance, at the top, heralding the advance of the Loma Blanca sand body.

So on, through the Yegua-Fayette, these cycles of advance and retreat took place many times, over approximately the same ground. On the whole, however, there was a gradual gulfward withdrawal of the sea throughout the Eocene. In late Eocene time sharp acceleration of this withdrawal of the sea brought the era to a close, and stopped the recurring cycles in the area under discussion.

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VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 275-284, 1 FIG.

GEOLOGICAL NOTES

DISCOVERY OF GAS IN ROCKINGHAM COUNTY, VIRGINIA[1]

PAUL H. PRICE[2]
Morgantown, West Virginia

The Great Eastern States Gas Company has recently completed a well on the C. L. Souder farm near Bergton, Rockingham County, Virginia. This location is in the strongly folded middle Appalachian region, and is approximately 70 miles east of any producing areas in West Virginia.

Gas was encountered at a depth of 1,300 feet with a rock pressure of approximately 400 pounds, volume unknown. The well was drilled to the depth of 2,992 feet, or 2 feet into the Oriskany sandstone, where gas was encountered and the well closed. The well then had a rock pressure of 1,150 pounds and an open flow of slightly more than 60 million cubic feet of gas.

A fractional distillation analysis of the gas, in the gas laboratory of the West Virginia Geological Survey, is as follows.

Sample collected from $5\frac{3}{16}$-inch casing, November 8, 1941

	Percentage
Methane	98.69
Ethane	.12
Propane+	.01
Nitrogen	1.18
Carbon dioxide	.00

Thv, in Btu per cu. ft. sat. 30 ins. Hg 60°F.	987
Specific gravity determined (air=1)	0.5604
Moisture content, percentage by volume (approximation only)	0.08

Although this is a small well and in a region where the carbon ratio is possibly 85, the presence of such pressures and volumes in the Valley and Ridge province of the folded Appalachians is worthy of note. The existence of many large open structures between its location and the producing areas on the west suggests the possibility of further similar discoveries.

[1] Manuscript received, December 13, 1941.

[2] State geologist of West Virginia.

WASHBURN FIELD, LASALLE COUNTY, TEXAS[1]

W. K. ESGEN[2]
Houston, Texas

The Washburn field is in east-central La Salle County, Texas, on the 130,000-acre Washburn Ranch, for which it is named.

The general area was probably first brought to the attention of geologists by Alexander Deussen in *U. S. Geological Survey Water-Supply Paper 375*, published in 1915. In this report Deussen inferred the presence of a fault through the southeastern part of the ranch from a study of the chemical analysis of the subsurface waters in the area. This fault was later found by the Sun Oil Company and still later by seismograph exploration. Deussen again called attention to the area in his *Professional Paper 126*, "Geology of the Coastal Plain of Texas West of Brazos River," published in 1924.

In 1925, the Mission Oil Company of Kansas City, Missouri, drilled a well in the southeastern part of the ranch to a depth of 3,013 feet, and abandoned it as a dry hole.

The Sun Oil Company spent considerable time and money in exploring the Washburn Ranch by several methods, the most important of which was probably core drilling. The core drilling, accomplished prior to 1927, revealed the presence of a small structure in the northwestern part of the ranch and a fault in the southeastern part. One well was drilled in the southeastern part of the ranch and abandoned as dry at a total depth of 3,917 feet on January 28, 1928.

In 1938, The Texas Company made a gravity-meter survey of the north-central and southeastern parts of the ranch. In 1939, the Independent Exploration Company shot the northwestern and southeastern parts of the ranch. To H. R. Cullen of Houston, Texas, goes the credit for the discovery of the Washburn field. His Washburn No. 1, located in the northwest part of the ranch, April, 1940, was completed as an oil well on August 28, 1940. It had an initial production of 60 barrels of 40° gravity, dark green oil and 9 barrels of brackish water, swabbing and flowing from a sand in the lower Wilcox from 5,416–5,432 feet. The well was plugged back from a depth of 8,300 feet, and, prior to final completion in the 5,400-foot sand, tested oil and water from sands at 4,860 feet and 5,060 feet.

Subsequently, intensive seismograph exploration and soil-analysis work was done, and two other wells, No. 2 and No. 3, were drilled.

[1] Manuscript received, December 13, 1941.

[2] Independent geologist. The writer wishes to express his thanks to H. R. Cullen, Judge John T. Pearson, the Humble Oil and Refining Company, and the Sun Oil Company for information obtained from them.

No. 2 was located 4,500 feet northeast and No. 3 was located 3,000 feet northwest of No. 1. No. 2 was completed as a flowing, fresh-water well from the Carrizo sand after being drilled to 5,561 feet and failing to find oil in commercial quantity in the Wilcox. No. 3 was commenced as a deep test and drilled to 11,042 feet. It has been temporarily abandoned after encountering high-gas pressure in the Cretaceous section. The pressure declined rapidly, indicating the origin was probably in the Cretaceous shales which contained a strong odor of oil in cores.

Cullen's Washburn No. 1-b, his fourth well, was located 6,265 feet southwest of his original discovery well after further seismograph and soil-analysis exploration. It was completed, November 6, 1941, through perforations at 5,530–5,550 feet in a lower Wilcox sand at 5,512–5,578 feet. Initial production was 405.72 barrels of 40.3° gravity, dark green oil per day with no water, flowing through the tubing on a ¼-inch choke. The gas-oil ratio was 425:1; tubing pressure, 525 pounds. The well was also completed as a gas well, flowing through the casing, which was perforated at 4,822–4,832 feet. The initial production from the gas sand was estimated as 20 million cubic feet per day, open flow. Total depth of the hole is 5,725 feet. The top of the Wilcox was encountered at a depth of 3,070 feet. The elevation of the well is 453 feet above sea-level. Prior to completion, the well was drill-stem tested in a sand at 5,136–5,155 feet, and 415 feet of 44° gravity, dark green oil was recovered in 25 minutes with 20-pound working pressure through ¼-inch top and ⅝-inch bottom chokes. Three drill-stem tests were made in the 5,500-foot sand as follows.

Test No. 1

5,512–5,524 feet. 25 minutes. ¼-inch top and ⅝-inch bottom chokes
Recovered 425 feet of 40° gravity, dark green oil
Working pressure, 23 pounds

Test No. 2

5,524–5,534 feet. 25 minutes. Same chokes as above
Recovered 1,680 feet of 40° gravity oil
Working pressure, 32 pounds

Test No. 3

5,534–5,554 feet. 20 minutes. Same chokes as above
Working pressure, 29 pounds. Shortly after tool was closed, well commenced flowing

This well marks the first completion of a good oil well in the lower Wilcox in Texas. It also marks the first good oil well in Texas from the entire Wilcox section where the Wilcox is encountered at such a shallow depth, with one exception (the Clay Creek salt dome in Washington County, Texas). The Washburn field, therefore, has an unusually important significance because it demonstrates possibilities for production from the so-called updip phase of the Wilcox group in an

enormous area along strike and paralleling the Gulf Coast across the entire state of Texas and connecting with the present shallow Wilcox production belt in Louisiana.

The causes of accumulation in the Washburn field are not clear as yet. Some small faulting is present in the Wilcox. Subsurface and geophysical information indicates the presence of older anticlinal or faulted structures in the area, with the present Wilcox production on the flanks due possibly to shore-line sedimentation and minor faulting.

The Yegua formation of the Claiborne group is on the surface. The subsurface formations encountered in Washburn No. 3 had the following thicknesses, as determined by the Humble Oil and Refining Company.

	Feet		Feet
Yegua	905	Navarro Taylor undifferentiated	2,017
Cook Mountain	495	Pecan Gap	330
Mt. Selman	1,770	Eagle Ford	90?
Carrizo	300	Buda	210?
Wilcox	1,140	Lower Cretaceous undifferentiated	300
Wilcox-Midway transitional zone	1,020	Edwards	420
Midway	980	Doubtful in age	42
Navarro (Escondido)	1,013		

A heavy sand section, which contains fresh to brackish water, is present throughout the Mt. Selman, Carrizo, and upper 700 feet of the Wilcox. Below this point the section gradually changes to a predominantly shale section with thin sands. The first showings of oil and gas in these sands are found 1,100 feet below the top of the Wilcox. Each of the four sand zones in the lower Wilcox, through a section of approximately 800 feet above the base, contained oil and (or) gas in the Washburn No. 1.

Determinations of porosity were run on cores from the four aforementioned sand zones in H. R. Cullen's Washburn No. 1 by the Humble Oil and Refining Company with the following results.

Depth in Feet	*Porosity Percentage*	*Description*
4,760–4,767	24.5	Fine-grained, tight sandstone
4,860–4,864	25.0	Fine-grained, tight sandstone
5,060–5,067	16.0	Hard, tight sandstone
5,417–5,425	22.5	Fine-grained, shale-streaked sandstone

The Midway, Navarro, and Taylor are shales and sandy shales, which are distinctly calcareous below 9,985 feet. The first limestone was found at 10,225 feet in Washburn No. 3. The top of the Edwards, as determined by the Humble Oil and Refining Company, is 10,580 feet. The section below this point is predominantly limestone. Due to lithologic differences between the formations in Washburn No. 3 and the typical fault-line section, and lack of diagnostic paleontologic

markers, it is difficult positively to identify the Cretaceous formations until more information is available.

Although the Washburn No. 1 is producing about 40 barrels of 42° gravity oil and 6 per cent salt water now on the pump, the No. 1-B, which is approximately 90 feet lower structurally than No. 1, is producing no water from what appears on Schlumberger correlation to be the same sand. It is impossible, therefore, to estimate the effective oil column or the water levels at the present time.

The following analysis of the oil from H. R. Cullen's Washburn No. 1 was made by the Sun Oil Company.

	A.P.I.	*Percentage*	*Gravity A.P.I.*
Gravity	40.5		
Paraffine		3.40	
Sulphur		0.11	
Gasoline (unit.–410°)		35.62	59.9
Light gas oil (410°–530°)		15.53	42.5
Heavy gas oil (530°-600°)		8.87	38.8
Bottoms		39.33	28.6
Loss		0.65	

McKEE AND WADDELL SANDS, SIMPSON GROUP, WEST TEXAS[1]

TAYLOR COLE,[2] C. D. CORDRY,[3] AND H. A. HEMPHILL[4]
Midland and Fort Worth, Texas

A committee[5] of the West Texas Geological Society has proposed names for the two sandstones of the Simpson group (Middle Ordovician) that now produce oil in West Texas.

The name McKee is proposed for the upper sandstone and the name Waddell for the lower sandstone. The McKee sand was first found productive in the Magnolia Petroleum Company's J. S. McKee No. 1-A, in Sec. 24, Block 9, H & GN Survey, Pecos County, Texas. The sandstone lies between the depths of 5,228 and 5,281 feet. The well was abandoned at 6,267 feet in the Ellenburger (Lower Ordovician); the elevation of the derrick floor is 2,385 feet above sea-

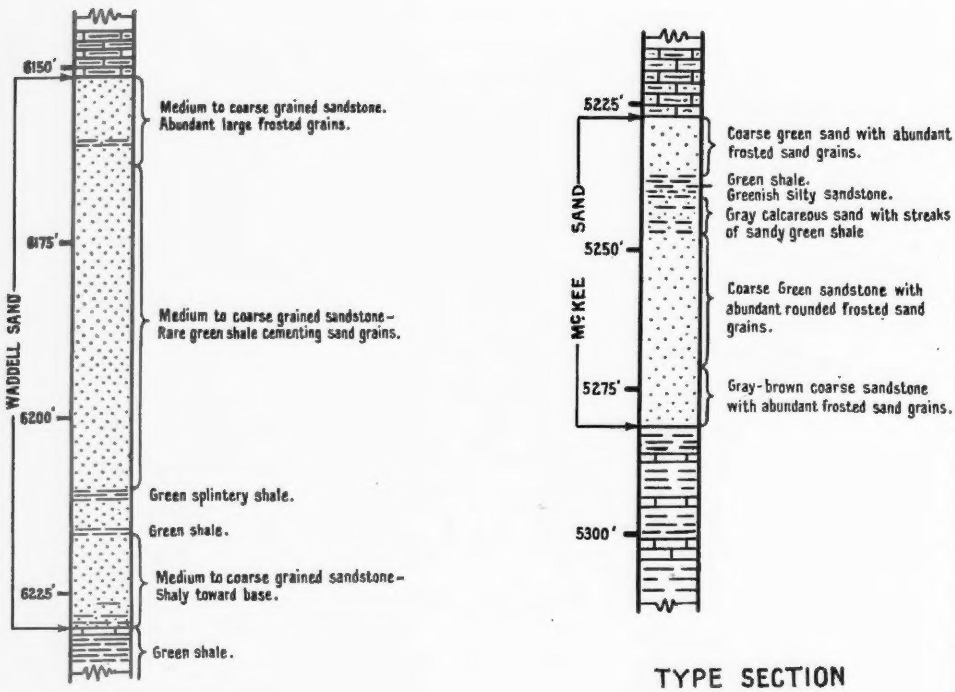
[1] Manuscript received, December 23, 1941.

[2] Research geologist, University Lands, Midland.

[3] Geologist, Gulf Oil Corporation, Fort Worth.

[4] Geologist, Magnolia Petroleum Company, Midland.

[5] Members: Taylor Cole, chairman; C. D. Cordry, Hugh Eley, H. A. Hemphill, Robert E. King, P. D. Moore, B. A. Ray, and E. Hazen Wood. Twenty geologists from various companies attended the committee's meeting on nomenclature, November 18, 1941.



TYPE SECTION
"WADDELL SAND"
GULF No 2, W.N.WADDELL ET AL
CRANE COUNTY, TEXAS

TYPE SECTION
"McKEE SAND"
M.P. CO. No 1-A, J.S.Mc KEE
PECOS COUNTY, TEXAS

FIG. 1

level. The top of the McKee sand occurs about 305 feet below the first red shale break in the Simpson and about 840 feet above the top of the Ellenburger dolomite, though this interval varies somewhat in a wide area. The McKee sand is the same as Bed 12, Zone D, of the Simpson group as described by Powers.[6] This sandstone is the chief productive bed of the Abell field.

The following description is a composite description derived from a study of the cores of near-by wells together with the cores and cuttings from the Magnolia McKee well No. 1-A. The cores and cuttings and sample log of this well are on file at the Magnolia Petroleum Company's office at Midland, Texas.

Type Section of McKee Sand

	Depths in Feet
Streaks of brown fine crystalline fossiliferous limestone with interbedded, frosted sand grains; and streaks of dark green shale	5,218–5,226
Top of McKee sand	
Coarse green sand, with abundant rounded, frosted sand grains	5,228–5,237
Hard, sandy, green shale	–5,239
Hard, greenish gray, silty sandstone with abundant rounded, frosted sand grains	–5,241
Hard, gray, calcareous sand, with streaks of sandy, green shale	–5,249
Coarse green sandstone with very abundant rounded, frosted sand grains	–5,271
Coarse gray to brown sandstone, with very abundant rounded frosted sand grains	–5,281
Base of McKee sand	
Dark green shale, with streaks of brown fossiliferous limestone	–5,290

(A diagram of this section is shown in Fig. 1.)

The name Waddell sand is proposed for the lower sandstone bed of the Simpson group which was first found productive in the Gulf Oil Corporation's W. N. Waddell *et al.* No. 1, Sec. 4, Block B-27, PSL Survey, Crane County, Texas. The sandstone lies between the depths of 5,965 and 6,040 feet. The same sandstone was found in the Gulf Oil Corporation's W. N. Waddell *et al.* No. 2, Sec. 17, Block B-27, PSL Survey. In this well the sandstone was found between the depths of 6,152 and 6,229 feet. As the sand zone was cored, it is from this well that the type section is described. This well has an elevation of 2,619 feet, was drilled to 6,709 feet, and was completed as a 149-barrel pumper at a plugged-back depth of 6,186 feet.

The top of the Waddell sand occurs about 480 feet below the top of the McKee sand and about 355 feet above the top of the Ellenburger (Lower Ordovician), although these intervals vary somewhat in a widespread area.

The Waddell sand is the same as Bed 9, Zone C, of the Simpson group described by Powers.[7]

[6] E. H. Powers, "Sand Hills Area, Crane County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 1 (January, 1940), Figure 4, p. 124.

[7] E. H. Powers, *op. cit.*

The cuttings and log of the Gulf's Waddell *et al.* well No. 2 are in the files of the Gulf Oil Corporation at Midland, Texas, and the cores are at the Gulf's McElroy Camp, Crane, Texas.

TYPE SECTION OF WADDELL SAND

	Depths in Feet
Greenish gray limestone and gray shale, intermixed and interstratified with small amounts of disseminated fine sand	6,143–6,152
Top of Waddell sand	
Medium- to coarse-grained sandstone, with abundant large, subrounded, frosted sand grains. The sandstone is tightly cemented with shaly and calcareous material at 6,152–6,155, 6,158–6,159, and 6,160–6,162	–6,163
Medium- to coarse-grained, green to gray, sandstone with abundant large frosted grains. The sandstone is cemented with various amounts of green shale and calcareous material	–6,200
Medium- to coarse-grained sandstone, tightly cemented with green shale and calcareous material	–6,204
Medium-grained, friable, angular, slightly porous sandstone	–6,210
Green, splintery shale	–6,212
Medium- to coarse-grained sandstone with varying amounts of shaly and calcareous cementing material	–6,220
Green shale with 20% medium-grained sandstone intermixed	–6,221
Medium- to coarse-grained angular sandstone, shaly near base	–6,229
Base of Waddell sand	
Green, thinly laminated, splintery shale	–6,231

(A diagram of this section is shown in Fig. 1.)

THE GEOLOGIST AND THE STATE DEFENSE GUARDS[1]

W. ARMSTRONG PRICE[2]
Corpus Christi, Texas

The sudden commencement of the war on the United States by the Axis powers presents an opportunity for geologists who are in deferred classes for military service, but who prefer that type of National Defense work to others, to find positions where their special abilities may be put to good advantage.

State Defense Guards have been formed in most of the states. These are State troops, but not, under present legislation, subject to transfer to the Federal service. The sudden onset of the war in America has led to local expansion of these Guard troops. New battalions will be formed in many cities and towns. Some states will now organize Guards which had not formerly done so.

The new Guard organizations will need new staffs. At least one position, possibly two, on the staff of a battalion or regiment can use qualifications developed by individual geologists.

[1] Manuscript received, January 7, 1942.

[2] Consulting geologist (William A. Price, 1st. Lt., Inf., T.D.G., S-3, Plans and Training Officer, 28th Battalion).

1. Geologists who are well acquainted with the areas of several counties around their places of residence can serve as the "S-3" on a military staff. The officer who holds this position is a "Plans and Training Officer," formerly known as an Operations Officer. This officer translates the general orders of the commander of the battalion or larger unit into detailed plans of operation for each of the several units of the command, such as companies or platoons. A good knowledge of the terrane is important. A geologist who has organized his knowledge of the local topography on a physiographic basis is better suited than one who knows it merely as a network of roads and trails or a mosaic of formation outcrops. In addition to the employment of his physiographic knowledge, he must learn the military manuals and military techniques applicable to Defense Guard work. These do not include as much of the tactics of the employment of large troop units in pitched battle as they do the operation of small units such as platoons or fixed guards. The time required will vary with the abilities of the associated staff officers, but should not be more than two to four evenings a week with one or two whole days a month. Occasional field maneuvers of several days may be planned for the future. The S-3 makes up monthly drill and training schedules for the rifle companies, headquarters specialists, and staff officers. In an Aviation Squadron, he has also the flight training.

2. The other staff position for which some geologists will find themselves well prepared is that of Intelligence Officer, "S-2." The assembling of military information is very similar to that of assembling the data for geological problems, especially the data of petroleum production and subsurface interpretations. Oil scouts, directors of oil-company record departments—provided they have come up through outdoors scouting work—and other administrative co-ordinators of data from widespread sources, especially if they are outdoors men, will make good intelligence officers. The ability to keep their mouths shut and let the other fellow talk is also important here.

If the geologist wishing to join a Guard organization has no opportunity to secure a staff officer's position, he can be a helper or understudy for such an officer. The best position from which to help the battalion staff officers is as a member of the Headquarters Detachment. The corresponding organization in a regiment is the Headquarters Company.

The procedure in seeking an opportunity to assist the Guard organizations is to apply in person to the commanding officer of the battalion or larger unit. If there is locally an ex-Army officer who is steering the formation of a new Guard unit, but not himself the com-

manding officer of it, apply to him. Subordinate commanders, such as commanders of companies and platoons or squads, may not know the needs of the staff or the qualifications needed for staff officers and their aides.

The State Defense Guards are organized along strictly military lines. They study the Army manuals, follow the new Army drill, are armed with Army rifles and side arms, will have some of the new arms, such as riot guns, sub-machine guns, *et cetera*. They will probably all adopt radio-telephone voice communication, as has the Texas Defense Guard. Hence, amateur radio operators holding licenses are much needed by the State Guards.

The State Defense Guards are not paid. To date, most of them buy their own uniforms, unless local funds are raised for their purchase. Up to the present they have used family automobiles in maneuvers and in reporting to drill. The physical qualifications, age limits, and reasons for resigning are less strict than in the U. S. Army. The Guard is a citizen army, subject to call only in emergencies so acute that the already established police, fire-fighting organizations and local watchmen can not cope with it. The Guard will not be a part of the Civilian Defense Organization and a Guard member can not hold at the same time a position under the Office of Civilian Defense. The two services are, however, to be closely co-ordinated in each locality where both are organized.

CORRECTION
RELATIONSHIP OF CRUDE OILS AND STRATIGRAPHY IN PARTS OF OKLAHOMA AND KANSAS

"Relationship of Crude Oils and Stratigraphy in Parts of Oklahoma and Kansas," by L. M. Neumann, N. W. Bass, R. L. Ginter, S. F. Mauney, Charles Ryniker, and H. M. Smith, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9 (September, 1941), pp. 1801–09.

Add to the authors the name of Thomas F. Newman, geologist of the Stanolind Oil and Gas Company, Tulsa, Oklahoma.

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VOL. 26, NO. 2 (FEBRUARY, 1942), P. 285

DISCUSSION

OBSERVATIONS ON ACCUMULATION OF FREE OIL[1]

P. C. DEAN[2]
Fort Worth, Texas

The paper, "Deposition of Free Oil by Sediments Settling in Sea Water," by O. A. Poirier and George A. Thiel appearing in the December, 1941, *Bulletin*, prompts me to describe two miniature oil deposits that I have observed in the "laboratory" of nature.

The first deposit was observed at Little Rock, Arkansas, in 1921, and occurred on a sand beach which formed the outer bank of a broad bend in the Arkansas River. The deposit, actually a miniature oil field, was approximately 200 feet long and 5 or 10 feet wide and paralleled the river.

The "pay" occurred at a depth of about one foot, and the oil would rise and "slop over" when holes were punched in the beach. The "pay" was about 2 inches thick and, along with the oil, contained sticks, leaves, and other drift material. The sand above and below was clean sand.

The oil, no doubt, had floated down the river from the Oklahoma oil fields, a common sight during the spring floods of 1921, and had been deposited by the current of the stream on the outer curve as the river receded. The deposit was subsequently covered by more sand, perhaps along with another rise in the river.

The second miniature deposit observed was at a slush pit in Eastland County, Texas. I had made some calculations as to the amount of oil and water in the pit when the oil uniformly covered the water about an inch in depth. The next morning, however, a strong wind had blown the oil 2 inches deep against one bank, leaving only water showing on the windward side. The sandy bank had soaked up a sizable amount of the oil so that when the pit dried there remained a miniature oil deposit along the "shore line."

The features observed in these miniature oil accumulations correspond in many ways with conditions found in many oil fields to-day, notably sand fields. If oil may be deposited as a sediment, as suggested by Poirier and Thiel, then might not the winds and currents be forces aiding in its accumulation and deposition?

[1] Manuscript received, January 10, 1942.

[2] Dean Brothers, geologists and oil producers.

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VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 286-289

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and available, for loan, to members and associates.

ANNUAL REVIEWS OF PETROLEUM TECHNOLOGY, BY THE INSTITUTE OF PETROLEUM

REVIEW BY W. P. HAYNES[1]
New York City

Annual Reviews of Petroleum Technology, Vol. 6 (covering 1940). Published by The Institute of Petroleum, The University, Birmingham, England. Paper, 318 pp., 6×9 inches. Price, 11s, or $2.50 (including postage).

The Institute of Petroleum has recently published its annual volume of *Reviews of Petroleum Technology*, covering the year 1940, in spite of the many difficulties due to the unsettled world conditions, and F. H. Garner, the editor, and his associates are to be congratulated upon securing so many good articles for this volume which has only 125 pages less than last year.

There are eighteen subject headings covering about the same broad range as in previous years. The subjects of "Petroleum Geology" and "Regional Geology and Development in the United States" have been very satisfactorily summarized by A. I. Levorsen and W. A. Ver Wiebe, respectively, and G. H. Scott has covered the year's developments in "Production Engineering." L. W. Storms, Jr., has given a good résumé of production matters ranging from "Well Completions" to "Proration."

The subject of "Drilling and Development of U. S. A. Fields" is treated in a well illustrated article by M. T. Archer, which includes description of equipment and methods employed in the various fields as well as statistical data, and L. S. Dawson has covered the items of "Drilling Mud, Heaving Shale and Cementing" in this chapter.

Other subjects dealt with are: "Transportation and Storage" (5 pages); "Natural Gas" (9 pages); "Cracking" (30 pages); "Alternative Fuels, including Carbonization, Hydrogenation and Synthetic Processes" (26 pages); "Motor Benzole" (23 pages); "Analyses and Testing" (14 pages); "Gas, Diesel and Fuel Oils" (3 pages); "Asphaltic Bitumen and Road Materials" (11 pages); "Special Products" (27 pages); "Petroleum Literature in 1940" (12 pages); "Petroleum Statistics" (18 pages); and "Lubricants and Lubrication" (33 pages).

At the end of each article is a bibliography which includes the more important contributions to the subject, and a subject and name index is given in the final ten pages. This is therefore a very convenient reference to enable the reader to put his hands readily upon the various authoritative articles covering the very broad range of subject matter included under the title "Petroleum Technology."

From this brief summary it will be noted that the emphasis of The Institute of Petroleum continues to be in the field of refining and manufacturing of products as is so often illustrated by articles in their bulletin. The first part of the present volume, however, should be of considerable interest to A.A.P.G. readers.

[1] Standard Oil Company of New Jersey. Manuscript received, December 24, 1941.

MARINE ECOLOGY AS RELATED TO PALEONTOLOGY, BY THE NATIONAL RESEARCH COUNCIL

REVIEW BY WALTER H. BUCHER[1]
Cincinnati, Ohio

Marine Ecology as Related to Paleontology, by the National Research Council (1941). 52 mim. pp. Price, $0.15.

The first report of the subcommittee on the Ecology of Marine Organisms, Committee on Geologic Research, has recently been issued by the National Research Council. It is a mimeographed bulletin of 52 pages, containing material presented, May, 1941, at the annual meeting of the Division of Geology and Geography. Most of the data in the report were obtained by the subcommittee in a canvass of individuals and institutions interested in marine ecology as related to paleontology.

The report attempts to present a picture of current and recently completed activities together with an annotated bibliography of a number of recently published papers. The Division of Geology and Geography wishes to give the report a fairly wide distribution in the belief that it will be found useful by paleontologists. Copies have been sent to individuals and to libraries, particularly those in the geological departments of colleges and universities. A limited number of copies are on hand and will be mailed to those desiring them. Requests should be addressed to the Division of Geology and Geography, National Research Council, 2101 Constitution Avenue, Washington, D. C., accompanied by 15 cents to cover cost of postage and handling.

[1] Department of Geology, University of Cincinnati. Manuscript received, January 7, 1942.

RECENT PUBLICATIONS

CALIFORNIA

*"A Contribution to California Oil and Gas History," by Walter Stalder. *California Oil World*, 1st Issue, Pt. II (Los Angeles, November 12, 1941). 96 pp., illus. Early history of the oil and gas industry.

CANADA

*"Potential Oil Fields of Western Canada," by Campbell M. Hunter. *Canadian Oil and Gas*, Vol. 2, No. 5-6 (Toronto, November-December, 1941), pp. 7-9. An address to the Oil Industries Club in London.

GENERAL

*"Discovery Trends Indicate New Prospecting Methods Needed," by Esme Eugene Rosaire. *Oil Weekly*, Vol. 104, No. 3 (Houston, December 22, 1941), pp. 32-34; 6 charts.

*"Trends in Petroleum Geology," by A. I. Levorsen. *Econ. Geol.*, Vol. 36, No. 8 (Lancaster, Pennsylvania, December, 1941), pp. 763-73.

*"Principles of Sedimentation and the Search for Stratigraphic Traps," by W. C. Krumbein. *Ibid.*, pp. 786-810; 7 figs.

"Coal Paleobotany," by Reinhart Thiessen and George C. Sprunk. *U. S. Bur. Mines Tech. Paper 631* (November, 1941). 56 pp., 44 figs. For sale by Supt. Documents, Govt. Printing Office, Washington, D. C. Price, $0.15.

*"Radioactivity of Ocean Sediments. IV. The Radium Content of Sediments of the Cayman Trough," by C. S. Piggott and Wm. D. Urry. *Amer. Jour. Sci.*, Vol. 240, No. 1 (New Haven, Connecticut, January, 1942), pp. 1–12; 3 figs., 2 tables.

*"The Distribution of Helium and Radioactivity in Rocks. II. Mineral Separates from the Cape Ann Granite," by N. B. Keevil. *Ibid.*, pp. 13–21; 4 tables.

ILLINOIS

Oil and Gas Map of Illinois. Size, 30×51 inches. Scale, approx. 1 inch = 8 miles. Printed in three colors. State Geological Survey, Urbana. Price, $0.35.

*"Rôle of Fundamental Geologic Principles in the Opening of the Illinois Basin," by Alfred H. Bell. *Econ. Geol.*, Vol. 36, No. 8 (Lancaster, Pennsylvania, December, 1941), pp. 774–85; 2 figs.

"Surface Structure Map of Shelby, Effingham, and Fayette Counties," by J. M. Weller and A. H. Bell. "Explanation and Summary," by William A. Newton. *Illinois Geol. Survey R. I. 76* (Urbana, December, 1941). 21 pp., 1 pl. Price, $0.25 plus $0.045 postage.

"Chester Ostracodes of Illinois," by C. L. Cooper. *Ibid., R. I. 77.* 101 pp., 14 pls. Price, $0.25 plus $0.015 postage.

INDIANA

*"The Devonian Formations of Indiana. Part I. Outcrop in Southern Indiana," by T. A. Dawson. *Indiana Div. Geol.* (Indianapolis, September, 1941). 48 pp., 20 photographs, 4 folded charts, sections, and map.

LOUISIANA

*"Prolific Sands Found in the Chacahoula Field [Lafourche Parish]," by Cyril K. Moresi. *Oil*, Vol. 1, No. 11 (New Orleans, December, 1941), pp. 16–18; 2 figs., 1 table.

NEVADA

*"The Nevada Early Ordovician (Pogonip) Sponge Fauna," by R. S. Bassler. *Proc. U. S. Nat. Museum*, Vol. 91, No. 3126 (Washington, 1941), pp. 91–102; Pls. 19–24.

TEXAS

"Petroleum Engineering Study of the Anahuac Field, Chambers County, Texas," by Charles B. Carpenter and H. J. Schroeder. *U. S. Bur. Mines R. I. 3579* (1941).

*"Ordovician Conodonts of the Marathon Basin, Texas," by Roy W. Graves, Jr., and Samuel Ellison. *Bull. Univ. Missouri School Mines and Met.*, Vol. 14, No. 2, Tech. Ser. (Rolla, September, 1941). 26 pp., 3 pls. of fossils, 2 figs.

*"Lower Pennsylvanian (Dimple Limestone) Conodonts of the Marathon Region, Texas," by Samuel Ellison and Roy W. Graves, Jr. *Ibid.*, Vol. 14, No. 3 (December, 1941). 21 pp., 3 pls., 1 fig.

TURKEY

*"The Stratigraphical Distribution of the Genera Orbitoides and Omphalocyclus in Southeastern Turkey," by S. W. Tromp. *Maden Tetkik ve Arama Enstitüsü Mecmuasi*, Sene 6, Sayi 3/24 (Ankara), 1941, pp. 366–70.

WYOMING

"Geologic Map of Hamilton Dome and Wagonhound Anticline, Hot Springs County, Wyoming," by W. B. Kramer and Robert McMillan. *U. S. Geol. Survey P. N. 171,719* (January 7, 1942). 2 mim. pp. describing the map, which is printed on a scale of 1 inch = 1 mile. Map is available free at offices of the Survey, Washington, D. C.; Room 224, U. S. Customhouse, Denver, Colorado; Room 305 Federal Building, Casper, Wyoming; and Room 201, Federal Building, Thermopolis, Wyoming.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 16, No. 1, January, 1942.

"Cenozoic Irregular Echinoids of Eastern United States," by C. Wythe Cooke.

"The Permian Algal Genus *Mizzia*," by J. Harlan Johnson and M. E. Dorr.

"Marine Miocene Mollusks from Cajon Pass, California," by W. P. Woodring.

"Eocene and Oligocene Coral Faunas of Washington," by J. Wyatt Durham.

"Some Claiborne Eocene Ostracoda of the Genus *Cytheridea* from the Gulf Coast," by Morton B. Stephenson.

"New Middle Eocene Gastropods from California," by Bruce L. Clark.

"Pennsylvanian Scaphopoda and Cephalopoda from New Mexico," by John A. Young, Jr.

"Jurassic Corals from the Smackover Limestone, Arkansas," by John W. Wells.

"Notes on the Cephalopod *Lambeoceras lambei* from Manitoba," by E. Leith.

"New Restoration of a Hooded Duck-Billed Dinosaur," by C. M. Sternberg.

"Dry-Peel Technique," by R. M. Sternberg and H. F. Belding.

"*Aligerites*, New Name for *Aliger* Howell, Preoccupied," by B. F. Howell.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 290-300, 3 FIGS.

THE ASSOCIATION ROUND TABLE

TECHNICAL SERVICE—AIR CORPS

Many geologists who anticipate entering military service are eligible for appointment as Aviation Cadets. In addition to air crew training, several courses of training for ground duty are offered.

Requirements

Age.—18 to 26 inclusive
Single men, or married men whose dependents have sufficient means of support
Physical requirements.—The regular requirements for army commission and extended active duty

Branches of Training Offered

Engineering.—For men who have completed 3 years of engineering in college
Communications.—Men who have completed 2 full years of college engineering, or have 2 years of general college training and an amateur radio license
Photography.—3 years of chemistry or geology in college, preferably with professional or considerable amateur experience (This branch is temporarily closed to applications)
Meteorology.—College graduates in sciences and engineering who have completed courses in differential and integral calculus and physics, including heat and thermodynamics

Training Period

12 to 28 weeks at various army ground schools

Commission

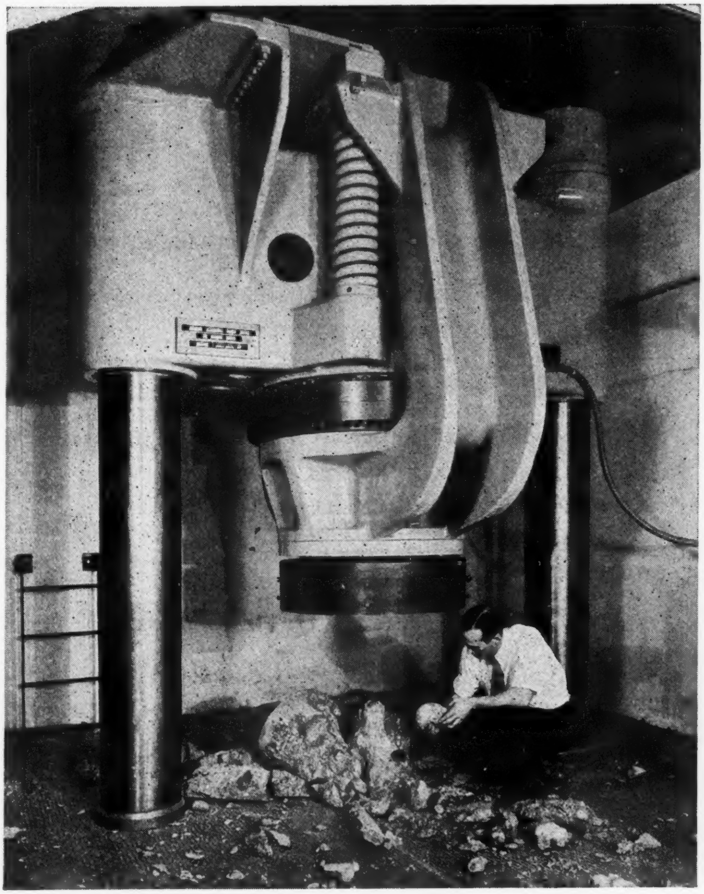
Upon successful completion of any of the prescribed courses, cadets are commissioned second lieutenants, Air Corps Reserve

Salary

As cadets, during training period, $75 per month and certain allowances
As second lieutenants, after completion of training, $183 per month and allowances (ground duty); $245 per month (flight pay)

Applications

Applications should be submitted in triplicate on WD AGO Form #60, accompanied by certified copy of birth certificate and three letters of recommendation to the commanding General of the Corps Area or to the nearest Aviation Cadet Examining Board.



The four million-pound hydraulic compression testing machine of the United States Bureau of Reclamation, Department of the Interior, at Denver. This is one of many pieces of engineering equipment that can be seen in the laboratories of the bureau during the annual convention of the American Association of Petroleum Geologists at Denver, April 22–24, 1942. The field headquarters for all Government reclamation activities is in Denver, its more than one thousand engineers comprising one of the world's largest engineering offices. In 39 years the Reclamation Bureau has built 145 dams, 23 power plants, and 83 reservoirs that conserve 60,000,000 acre-feet of water (20,000 billion gallons).

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REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: A. I. LEVORSEN (1943)

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JOINT ANNUAL CONVENTION, DENVER, APRIL 22–24, 1942

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
SOCIETY OF EXPLORATION GEOPHYSICISTS

EDGAR W. OWEN[1]
San Antonio, Texas

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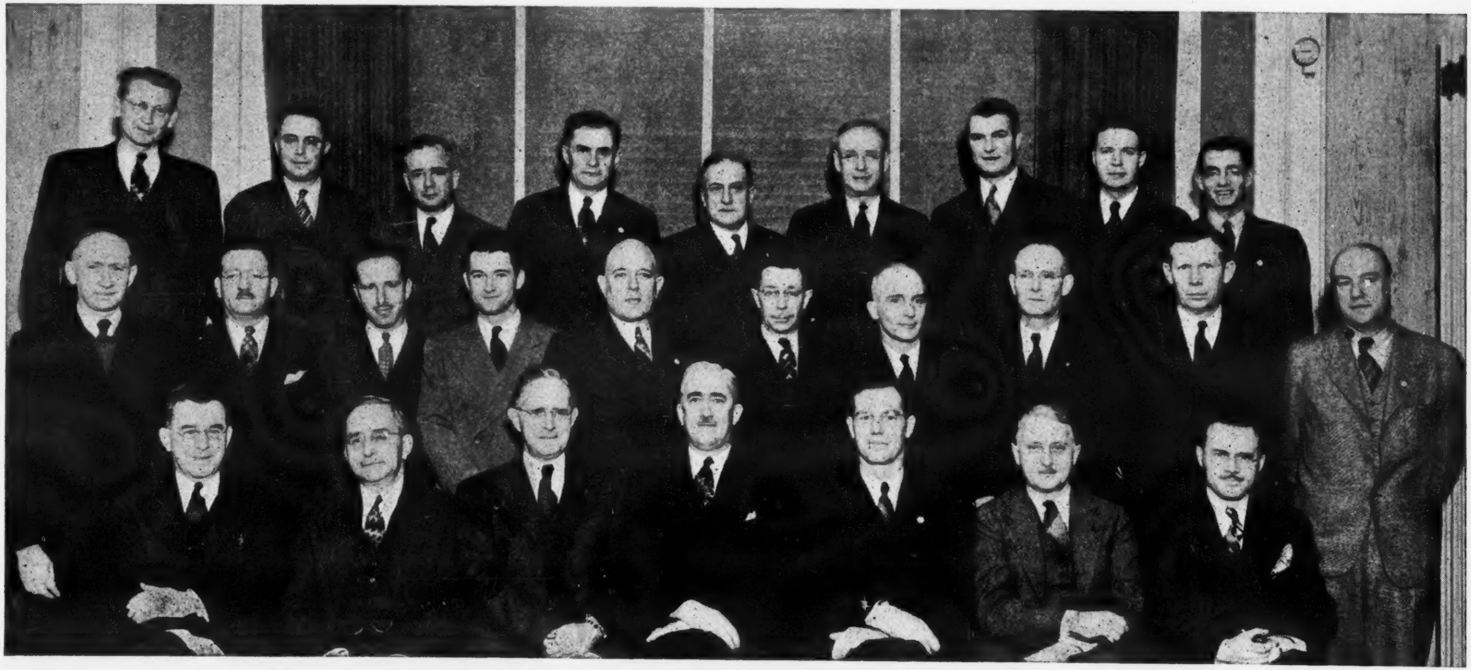
Educational exhibits	Warren O. Thompson, University of Colorado
Society of Economic Paleontologists and Mineralogists	J. Harlan Johnson, Colorado School of Mines
Society of Exploration Geophysicists	C. A. Heiland, Colorado School of Mines

[1] Chairman, executive committee, A.A.P.G.



Mile High Photo Co., Denver

Group of officers and committeemen who met in Denver, January 17, to arrange for the joint annual meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, which is scheduled for April 22–24, 1942, at the Cosmopolitan Hotel, Denver, Colorado. Top row, left to right: Edgar W. Owen, president, A.A.P.G., Robert E. Landon, Chas. E. Erdmann, 1st vice-president, Rocky Mountain Association, Everett S. Shaw, C. E. Shoenfelt, Harry A. Aurand, Dewey Sample, H. E. Christensen, president, Rocky Mountain Association, W. C. Toepelman. Middle row, left to right: F. M. Van Tuyl, chairman, Front Range field trips, Robert Spratt, Jay O. Myers, R. Maurice Tripp, H. W. C. Prommel, Ross L. Heaton, W. B. Kramer, David B. Miller, John W. Vanderwilt, chairman, Western Slope field trips, Earl B. Noble, vice-president, A.A.P.G. Front row, left to right: A. E. Brainerd, chairman, technical program, T. S. Harrison, chairman, reception, J. Harlan Johnson, chairman, S.E.P.M., C. E. Dobbin, general chairman, W. O. Thompson, chairman, educational exhibits, W. A. Waldschmidt, chairman, publicity, C. A. Heiland, chairman, S.E.G.

ANNOUNCEMENT

The twenty-seventh annual meeting of the Association will be held in Denver, Colorado, April 22, 23, and 24, 1942. Headquarters will be at the Cosmopolitan Hotel. The sixteenth annual meeting of the Society of Economic Paleontologists and Mineralogists and the twelfth annual meeting of the Society of Exploration Geophysicists will be conducted jointly with that of the Association. The Rocky Mountain Association of Petroleum Geologists is serving as host for the meetings, but all arrangements are under the direction of the executive committees of the three national organizations.

WAR-TIME READJUSTMENT

It is believed that the need for the meetings is greater than ever before and that a great deal can be accomplished by a thorough study of the conditions which the war has imposed upon us and by a concerted effort to adjust our scientific and technical resources to those requirements. The sacrifice of the time, energy, and expense entailed will be justified only by the accomplishment of constructive work which will increase the effectiveness of our participation in the war effort. Every convention activity will be directed to that end, and customary features which do not contribute to that purpose will be eliminated.

SPECIAL SPEAKERS

Every effort is being made to obtain participation in the program by nationally recognized authorities who can analyze the requirements to be made of the petroleum industry and appraise our resources for meeting them. Such addresses are planned to serve as the basis for a series of conferences on possible improvements in technique and employment of personnel.

CONFERENCES ON WAR EFFORT

Special conferences have been arranged to consider various essential problems.

RESEARCH COMMITTEE SURVEY OF OIL-DISCOVERY METHODS. Tuesday evening, April 21, 8:00–11:00 P.M. This meeting will consist of a symposium of ideas and suggestions for maintaining an adequate oil-discovery rate in the United States. Oil discovery is the major concern of our profession and a cross section of its opinion should be of interest to all of our members and also provide a reserve of ideas which may be drawn upon by anyone interested in this problem.

JOINT CONFERENCE OF THE A.A.P.G., S.E.G., AND S.E.P.M. ON THE APPLICATION OF GEOLOGY AND GEOPHYSICS TO WAR AND POST-WAR PROBLEMS OF THE PETROLEUM INDUSTRY. Wednesday, April 22, 2:00–5:00 P.M. Under the co-chairmanship of a geologist and a geophysicist, an examination will be made of the emergency requirements for the various types of oil, distillate, and petroleum products, and how these requirements may be met most effectively in the several principal oil provinces by the application of geological and geophysical technique. This meeting will replace the usual technical program for the afternoon, and all members are expected to participate in the discussion.

CONFERENCE ON WAR-TIME PERSONNEL PROBLEMS. Wednesday, April 22, 8:00–10:00 P.M. A limited group, composed of the national service committee, the chief geologists and geophysicists of the large oil companies, or their delegates, and the district representatives of the A.A.P.G., will study emergency problems of personnel. The subjects to be considered may include:

(a) The proper scope of requests for selective service deferment
(b) The temporary employment of technical men to fill vacancies left by men going into military service
(c) Readjustment of personnel to meet emergency requirements
(d) Other similar problems which may be apparent at the time

REGISTRATION

Members and guests should register immediately after obtaining hotel accommodations. The registration counter will be in the Lobby, first floor, of the Cosmopolitan Hotel, and it will be open from Monday noon until the conclusion of the convention. There will be no registration fee.

EXHIBITS

Scientific exhibits of timely interest will be displayed in the Blue Room and near-by corridors of the Cosmopolitan Hotel. Exhibits from State geological surveys and educational institutions are invited. Supervision of such exhibits will be undertaken co-operatively by members of the participating institutions who are present at the meeting, under the direction of the chairman for educational exhibits.

The annual exhibit of laboratory and field exploration methods and apparatus will occupy a large part of the Mezzanine Floor of the Cosmopolitan Hotel.

The entire display of up-to-date educational and technical equipment is expected to be specially significant and important this year.

PRE-CONVENTION SESSIONS

Attention is directed to the meetings of the business committee and various standing and special committees of the A.A.P.G., which are scheduled for Tuesday, April 21.

CONFERENCES, TUESDAY, APRIL 21, 2:00–5:00 P.M.

Origin of oil: Monroe G. Cheney and W. P. Rand, co-leaders
Migration and accumulation of oil: F. M. Van Tuyl and Ben H. Parker, co-leaders
Oil-field waters: L. C. Case, leader
Sedimentation: F. W. Rolshausen and W. C. Krumbein, co-leaders
Relation of oil analyses to stratigraphy: L. M. Neumann and N. W. Bass, co-leaders

The research committee conference groups which will meet on Tuesday afternoon are open to all interested members. Of outstanding interest is the general conference of the research committee on "Oil-Discovery Methods" to be held in the Ball Room of the Cosmopolitan Hotel on Tuesday evening. As usual, this meeting will be open to everyone in attendance at the convention.

By Courtesy of the Denver Convention and Visitors Bureau

Explanation of cut on opposite page.

FIELD TRIPS

Short field trips will be conducted to localities of outstanding geologic and scenic interest at the near-by Rocky Mountain Front on each day of the meeting. On Saturday and Sunday, April 25 and 26, a field trip will go by bus over Berthaud Pass to Glenwood Springs and Rifle, Colorado, returning to Denver via Loveland Pass. A very comprehensive view of Rocky Mountain structure, stratigraphy and scenery will be presented. California members taking the trip can resume their homeward journey from the western end with little loss of time. Plans for this trip are flexible, and final arrangements will depend largely upon the number of persons wishing to participate, and upon weather conditions. The estimated cost for the trip will be \$12–\$15 per person.

ENTERTAINMENT

Due to the unusual amount of work to be carried on during the convention, no special entertainment features are being planned. Denver affords plentiful facilities for entertainment during whatever leisure time may be available.

GOLF

The usual golf tournament will be omitted.

HOTELS

Hotel reservations should be made by each person directly with the hotel of his choice. Request the hotel for confirmation. The hotel committee, Charles S. Lavington, chairman, Continental Oil Company, Denver, will be glad to give advice about hotel accommodations.

COSMOPOLITAN HOTEL (Headquarters). All rooms with bath

Single	\$ 3.30	\$ 3.85	\$ 4.40	\$ 5.50
Double	5.50	6.60	7.70	8.80
Suites	10.00	12.00	15.00	18.00

BROWN PALACE HOTEL (Across street from headquarters). All rooms with bath

One person	\$ 3.85	\$ 4.40	\$ 5.50	\$ 6.60	
Two persons, double bed		5.50	6.60	7.70	
Two persons, twin beds	6.60	7.70	8.80	9.90	
Two room suites	10.00	12.00	14.00	15.00	\$16.00

SHIRLEY-SAVOY HOTEL (One block from headquarters)

Single room with bath, on court, 1 or 2 persons		\$ 2.50
Single room with bath, outside exposure, 1 or 2 persons		3.50
Room, twin beds, with bath—on court		3.50
Room, twin beds, with bath—outside exposure		4.50
Room with double bed, room with twin beds, connecting bath, for four—on court		6.00
Same with outside exposure	\$7.00	8.00
Two-room suite with bath	8.00	10.00
Also special rates for several students in large rooms		

Air view of Denver, Colorado, looking northwest. In the foreground is Denver's \$11,000,000 Civic Center. The State Capitol is at the lower right, the City Hall at the left, forming the west side of the plaza. The large white building with the colonnade, at the upper right, is the Post Office, and the white building diagonally across the street, east of it, is the United States Customhouse, where the Geological Survey and other Government organizations are housed. The Union Depot is at the left top edge of the picture between viaducts crossing the South Platte River. The triangular building at the right of the center of the picture is the Brown Palace Hotel and east of it across Broadway is the Cosmopolitan Hotel, the headquarters of the A.A.P.G. twenty-seventh annual meeting, April 22–24, 1942. One block south of the Cosmopolitan is the Shirley-Savoy Hotel.

ALBANY HOTEL (4½ blocks from headquarters). All rooms with bath and radio

Single	$3.00	$3.50	$4.00	and up
Double, twin beds	5.00	6.00	7.00	and up
Albany Annex				
Single	2.00	2.50	and up	
Double, twin beds	5.00		and up	

TRANSPORTATION

There is no special convention rate in effect on the railroads. You should see your local ticket agent about rates that may be available.

TECHNICAL PROGRAM

On Wednesday morning, April 22, a joint session of the A.A.P.G., S.E.G., and S.E.P.M. will hear their three presidential addresses and special addresses on war requirements of the petroleum industry by authorities of national reputation.

The usual Wednesday afternoon technical session will be replaced by the conference on "The Application of Geology and Geophysics to War and Post-War Problems of the Petroleum Industry," as outlined in a previous paragraph.

The Thursday morning and afternoon technical sessions will also be joint meetings of the A.A.P.G., the S.E.G., and the S.E.P.M. Technical papers of general interest to the members of all three organizations will constitute these programs.

On Friday, April 24, technical sessions of the three societies will be held separately. The more specialized geological, geophysical, and paleontological papers will be presented at these morning and afternoon meetings.

The entire technical program will be directed as far as possible toward a contribution to the war effort. It will be necessary that many important papers, which have been solicited and which will be prepared, shall be read by title. Every effort will be made to arrange for the presentation of all papers which have a direct application to the war program or bear on fundamental research and development problems. All other papers which record the results of scientific work are solicited for publication in the official bulletins of the three societies.

BIBLIOGRAPHY OF MILITARY GEOLOGY AND GEOGRAPHY

An 18-page pamphlet entitled *Bibliography of Military Geology and Geography* has been published recently by The Geological Society of America. This timely and useful information was prepared under the direction of W. H. BUCHER, chairman of the Division of Geology and Geography of the National Research Council. It is issued jointly by the Division and the G.S.A. The booklet is designed as a guide for the American geologists and geographers who wish to inform themselves concerning the ways in which their special training and experience may become useful in an armed conflict. This work is presented to the geologists of America by the Geological Society of America, and through the courtesy of that Society, free copies may be obtained postpaid at A.A.P.G. headquarters, Box 979, Tulsa, Oklahoma.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 2 (FEBRUARY, 1942), PP. 301-304

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CHESTER A. HAMMILL, consulting geologist of Dallas, Texas, died on December 7, 1941. He was one of the first members of the Association, his name being listed in the *Bulletin* of the Southwestern Association of Petroleum Geologists in 1917.

BERNARD H. LASKY, engineer and geologist, has moved his offices from the Commerce Building to 702 Mellie Esperson Building, Houston, Texas.

D. POPE MEAGHER is working for the Carter Oil Company in Mississippi. His address is Box 1490, Jackson, Mississippi.

JOHN R. SUMAN, president of the A.I.M.E., has an article, "Mineral Needs of a World at War," in the January issue of *Mining and Metallurgy.*

W. ARMSTRONG PRICE, consulting geologist, Corpus Christi, Texas, is WILLIAM A. PRICE, 1st Lt., Texas Defense Guard, S-3, Plans and Training Officer, 28th Battalion.

MALCOLM E. WILSON is executive vice-president of the General American Oil Company, Dallas, Texas.

MARVIN LEE, consulting geologist of Wichita, Kansas, is in Washington, D. C., in an oil-administrative position in the Department of the Interior.

Members desiring autographed copies of STANLEY HEROLD'S *Oil Well Drainage* should purchase them directly from the author at 811 West Seventh Street, Los Angeles, California, enclosing personal check for $5.00 per copy (plus 3 per cent for delivery in California) with their orders.

Newly elected officers for the Fort Worth Geological Society for 1942 are: president, J. B. LOVEJOY, Gulf Oil Corporation; vice-president, KARL A. MYGDAL, The Pure Oil Company; secretary-treasurer, RICHARD H. SCHWEERS, The Texas Company.

PAUL WEAVER, chief geophysicist of the Gulf Oil Corporation, Houston, Texas, addressed the New Orleans Geological Society at the St. Charles Hotel, New Orleans, Louisiana, December 1, on "How the Jurassic as Known from Mexico to Arkansas Helps to Understand Salt Domes in the Gulf Coast." On January 5, he addressed the Shreveport Geological Society on "Method of Formation of Large Salt Deposits."

New officers of the Rocky Mountain Association of Petroleum Geologists are: president, H. E. CHRISTENSEN, of The Texas Company; 1st vice-president, C. E. ERDMANN, of the United States Geological Survey; 2d vice-president, DON B. GOULD, of Colorado College, Colorado Springs; secretary-treasurer, RALPH D. COPLEY, 1006 United States National Bank Building, Denver. On January 5, C. S. MEESE, of the Eastman Oil Well Survey Corporation, talked before the Association on "Directional Drilling and Well Surveying."

MORGAN E. ROBERTS, district geologist for The Pure Oil Company at Fort Worth, Texas, died from a heart attack, December 30.

ADDISON YOUNG and MAX DAVID, geologists with the Landreth Production Corporation which has been acquired by the Stanolind Oil and Gas Company, have opened an office as consulting gelogists at Midland, Texas.

V. A. FROST, recently with the Mid-Continent Petroleum Corporation at Tulsa, Oklahoma, is now on the geological staff of the Ohio Oil Company.

CHARLES T. JONES, recently with the Stanolind Oil and Gas Company at Wichita, Kansas, is a captain in the Corps of Engineers at Fort Jackson, South Carolina. He may be addressed at 3719 Duncan Street, Columbia, South Carolina.

B. G. MARTIN, geologist with the Gulf Oil Corporation, Houston, Texas, is petroleum analyst under the Office of Petroleum Coordinator. He is to be stationed at Houston, District 3 headquarters. The region with which he is concerned includes West Texas, New Mexico, and the Panhandle.

E. G. WOODRUFF, geologist of Tulsa, Oklahoma, has donated his geological library of more than 1,700 titles to the Tulsa City Library.

C. C. MILLER, formerly with The Texas Company, is geologist of the Renwar Oil Company, Corpus Christi, Texas.

C. A. HEILAND, professor of geophysics at the Colorado School of Mines, Golden, Colorado, is the author of "Geophysics in War," comprising about 100 pages in the Colorado School of Mines *Quarterly*, Vol. 37, No. 1 (1942). The article contains 47 photographs, diagrams, and charts. The price is $1.00, payable to the Colorado School of Mines Department of Publications, Golden.

The 1942 Illinois Mineral Industries Conference will be held, October 30 and 31, on the campus of the University of Illinois, Urbana, according to M. M. LEIGHTON, chief of the Illinois State Geological Survey.

JACK D. MULLINAX, recently with the Continental Oil Company, Ponca City, Oklahoma, is taking a 3-month course of study in line of duty at Fort Belvoir Engineer School. Mullinax is a second lieutenant.

BRUCE L. CLARK, professor of paleontology at the University of California, gave two addresses on January 8, before the department of geology of the University of Michigan in Ann Arbor: "Tertiary Paleontology and Stratigraphy of the Pacific Coast," and "The Geologic Structure and Stratigraphy of California."

NORVAL BALLARD spoke on "Regional Geology of the Dakotas" at a meeting of the Tulsa Geological Society on January 19.

JOHN E. BLIXT was the speaker at the Rocky Mountain Association of Petroleum Geologists meeting held on January 19. His subject was "The Cut Bank Oil Field, Glacier County, Montana."

C. G. DINSMOOR may be addressed 1st Lt., 423rd Coast Art., Bn. (Comp) (AA), Commanding Btry. "D," A.P.O. #1004 c/o Postmaster, New York, N. Y.

New officers of the Michigan Geological Society are as follows: president, LEE C. LAMAR, Carter Oil Company, Mt. Pleasant; vice-president, A. J. EARDLEY, University of Michigan, Ann Arbor; secretary-treasurer, EDWARD J. BALTRUSAITIS, Box 811, Saginaw; business manager, GORDON H. PRINGLE, Ohio Oil Company, Mt. Pleasant.

The monthly meeting of the South Louisiana Geological Society was held on January 13 in Lake Charles, A. S. PARKS of Houston, Texas, spoke on "Basic Principles Underlying Recycling Operations." Officers elected for the coming year are: president, HARRY KILIAN, Union Sulphur Company, Sulphur; vice-president, COE S. MILLS, Ohio Oil Company, Lafayette; secretary, ROY A. PAYNE, Gulf Refining Company, Lake Charles; treasurer, GEORGE N. MAY, Union Sulphur Company, Sulphur.

New officers of the West Texas Geological Society are: president, RONALD K. DEFORD, Argo Oil Corporation; vice-president, WALTER G. MOXEY, Stanolind Oil and Gas Company; secretary-treasurer, W. LLOYD HASELTINE, Magnolia Petroleum Company, all of Midland, Texas.

J. WILLIAM GWINN, formerly with the Iraq Petroleum Company in Palestine, is with the West India Oil Company, San Jose, Costa Rica,

R. J. FORSYTH, formerly with the Seaboard Oil Company, is with Case, Pomeroy and Company, Inc., at Evansville, Indiana.

STANLEY W. WILCOX is with the Seismograph Service Corporation, 709 Kennedy Building, Tulsa, Oklahoma.

ROBERT J. GIVEN, recently with the Dapar Oil Company, Grand Rapids, Michigan, is a lieutenant at Selfridge Field, Mt. Clemens Michigan.

HENRY EMMETT GROSS, associate professor of petroleum engineering at Texas Agricultural and Mechanical College, College Station, Texas, has been appointed associate petroleum production analyst in the Chicago office of the Office of Petroleum Coordinator.

EARL A. TARVER has been appointed head of the geological department of the Superior Oil Corporation at Tulsa.

HERBERT M. GOODMAN, recently with the Shell Oil Company, Inc., is a second lieutenant, C. E., Company B, 35th Bn., E.R.T.C., Fort Leonard Wood, Missouri.

EDGAR W. OWEN, president, and EARL B. NOBLE, vice-president, of the American Association of Petroleum Geologists, met with representatives of the Rocky Mountain Association of Petroleum Geologists at the Cosmopolitan Hotel, Denver, Colorado, on January 17, to make arrangements for the twenty-seventh annual convention of the A.A.P.G., to be held at Denver, April 22–24, 1942. C. E. DOBBIN of the United States Geological Survey, general chairman of the Denver committee on arrangements, and twenty-three committeemen were present.

BERTRAND S. RIDGEWAY, district geologist for the Cities Service Oil Company, died at Mattoon, Illinois, January 22.

WALTER E. HOPPER, who resigned November 1, 1941, as senior petroleum geologist and engineer in charge, in the Oil and Gas Unit of the Securities and Exchange Commission and who has been in charge of the Tulsa field office of the Unit for the past 2 years, has announced the opening of an office as a consulting geologist at 512 National Mutual Building, Tulsa, specializing in the preparation of all data required to be filed by producers of oil and gas, under the OPC orders M 68 and P 98 and the Securities Act of 1933.

R. H. ALAGOOD, recently with the Landreth Producing Corporation, is employed by the Pure Oil Company, Corpus Christi, Texas.

FRANCIS P. SHEPARD, of the University of Illinois and the Scripps Institution of Oceanography, La Jolla, California, spoke before the Tulsa Geological Society, February 2, on "Oceanographic Investigations of Submarine Canyons."

EARL B. NOBLE, vice-president of the Association, of the Union Oil Company, Los Angeles, California, has appeared before several local geological societies recently, talking on Association affairs, and presenting moving pictures of recent trips in Central America.

RANDALL WRIGHT is in the United States Engineers office, M. & M. Building, Houston, Texas.

L. DON LEET, assistant professor of geophysics at Harvard University, spoke before the Tulsa Geological Society, January 26, on "Some Applications of Pure Seismology."

SAM H. KNIGHT, chairman of the department of geology at the University of Wyoming, spoke before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, February 2, on "The Physical Evolution of the Rocky Mountains."

JULIAN K. PAWLEY, formerly with the General Geophysical Company, is assistant to the chief geophysicist of the Standard Oil Company of Texas, at Houston.

Officers of the Society of Economic Paleontologists and Mineralogists for the administrative year following the annual meeting, which is to be held in Denver, Colorado, April 22–24, 1942, recently elected by mailed ballot are: president, HERSCHEL L. DRIVER, Standard Oil Company of California, Los Angeles; vice-president, PARKER D. TRASK, United States Geological Survey, Washington, D. C.; secretary-treasurer, H. B. STENZEL (re-elected), University of Texas Bureau of Economic Geology, Austin, Texas.

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ELFRED BECK
Geologist

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TULSA, OKLA.

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DENVER, COLORADO

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The Texas Company
1st Vice-President - - - - - C. E. Erdmann
U. S. Geological Survey
2nd Vice-President - - - - - Don B. Gould
Colorado College, Colorado Springs
Secretary-Treasurer - - - - Ralph D. Copley
1006 U. S. National Bank Building

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - George D. Putnam
Globe Oil and Refining Company
Vice-President - - - - - - William C. Imbt
Stanolind Oil and Gas Company
Secretary-Treasurer - - - - - - - Z. E. Stucky
Cities Service Oil Company
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - - - Lee C. Lamar
Carter Oil Company, Mt. Pleasant

Vice-President - - - - - - - - A. J. Eardley
University of Michigan, Ann Arbor

Secretary-Treasurer - - - Edward J. Baltrusaitis
Box 811, Saginaw

Business Manager - - - - Gordon H. Pringle
Ohio Oil Company, Mt. Pleasant

Meetings: Second Wednesday of month at 6:30 P.M., from November to April. Informal dinner followed by discussions. Meetings held in rotation, at Lansing, Mt. Pleasant, Ann Arbor, Grand Rapids. Visiting geologists are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

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Shell Oil Company, Inc., Centralia

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Gulf Refining Company, Mattoon

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The Ohio Oil Company, Marshall

Meetings will be announced.

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Vice-President - - - - - - - - Joseph Purzer
Phillips Petroleum Company

Secretary-Treasurer - - - - Van D. Robinson
Atlantic Refining Company, 1001 City Bank Bldg.

Meets the first Monday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

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Vice-President - - - - - - - - Coe S. Mills
Ohio Oil Company, Lafayette, La.

Secretary - - - - - - - - - - Roy A. Payne
Gulf Refining Company, Lake Charles, La.

Treasurer - - - - - - - - George N. May
Union Sulphur Co., Sulphur, La.

Meetings: Luncheon 1st Wednesday at Noon (12:00) and business meeting third Tuesday of each month at 7.00 P.M. at the Majestic Hotel. Visiting geologists are welcome.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - - J. B. Lovejoy
Gulf Oil Corporation

Vice-President - - - - - - Karl A. Mygdal
The Pure Oil Company

Secretary-Treasurer - - - Richard H. Schweers
The Texas Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - Carleton D. Speed, Jr.
Consulting Geologist, Second National Bank Bldg.

Vice-President - - - - - - Donald M. Davis
Pure Oil Company

Secretary - - - - - - - - Wayne Z. Burkhead
Union Oil Company of California
1134 Commercial Building

Treasurer - - - - - - James W. Kisling, Jr.
Amerada Petroleum Corporation, Esperson Bldg.

Regular meeting held every Thursday at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
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Deep Rock Oil Company

Secretary-Treasurer - - - - - Dolphe E. Simic
Cities Service Oil Company

Luncheons and evening programs will be announced.

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TEXAS

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Humble Oil and Refining Company, Corpus Christi

Secretary-Treasurer - - - - W. W. Hammond
Magnolia Petroleum Company, 1709 Alamo National Building, San Antonio

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

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Argo Oil Corporation

Vice-President - - - - - Walter G. Moxey
Stanolind Oil and Gas Company

Secretary-Treasurer - - - - W. Lloyd Haseltine
Magnolia Petroleum Company

Meetings will be announced

WEST VIRGINIA

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P.O. Box 1435

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Godfrey L. Cabot, Inc., Box 348

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Public Service Commission

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West Virginia Gas Corporation
Box 404, Charleston, W.Va.

Editor - - - - - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department
Box 1375, Charleston, W.Va.

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

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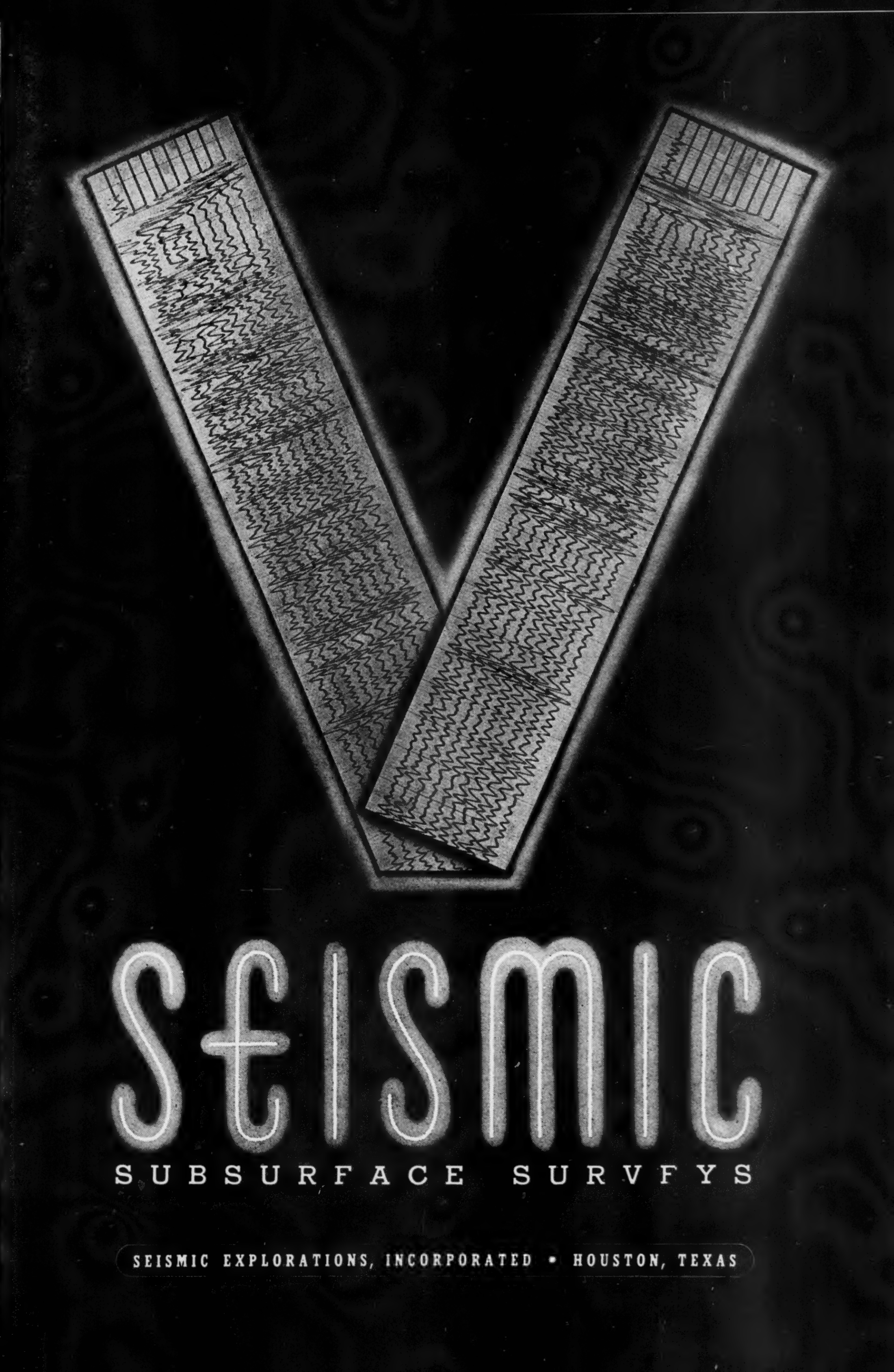
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